Message from the Steering Committee Chair

Welcome to the International Conference for Internet Technology and Secured Transactions (ICITST-2013), World Congress on Internet Security (WorldCIS-2013) and World Congress on Sustainable Technologies (WCST-2013) collocated conferences provides opportunity for academicians and professionals to bridge the knowledge gap and to promote research esteem.

The ICITST-2013 received 1241 papers from 96 countries of which 441 papers were accepted after the first review and 157 papers were finally accepted for presentation and 4 Workshops. The WorldCIS-2013 received 335 papers from 41 countries of which 103 papers were accepted after the first review and 49 papers were finally accepted for presentation. While WCST-2013 received 175 papers from 32 countries of which 63 were accepted after the first review and 30 papers were finally accepted for presentation. The double blind paper evaluation method was adopted to evaluate each of the conferences submissions. Please note that selected papers will be invited for publications in high impact International Journals.

Many people have worked very hard to make this conference possible. I would like to thank all who have helped in making ICITST-2013, WorldCIS-2013 and WCST-2013 a success. The Steering Committee and reviewers each deserve credit for their excellent job. I thank the authors who have contributed to each of the conferences and all our Keynote Speakers: Jeffrey J. Wiley, Professor David Stubbles, Dr. Tyson T. Brooks, Professor Yoon Seok Chang, Professor N.J. Hewitt and Dr John Littlewood for agreeing to participate in ICITST-2013, WorldCIS-2013 and WCST-2013. I also like to acknowledge my appreciation to the following organisations for their sponsorship and support: IEEE UK/RI Computer Chapter, Infonomics Society, Canadian Teacher Magazine and National Association for Adults with Special Learning Needs (NAASLN). It has been great pleasure to serve as the Steering Committee Chair for the three conferences. The long term goal of ICITST-2013, WorldCIS-2013 and WCST-2013 is to build a reputation and respectable conference for the international community.

On behalf of the ICITST-2013, WorldCIS-2013 and WCST-2013 Executive members, I would like to encourage you to contribute to the future of ICITST, WorldCIS and WCST as authors, speakers, panellists, and volunteer conference organisers. I wish you a pleasant stay in London, and please feel free to exchange ideas with other colleagues.

Professor Charles A. Shoniregun
ICITST-2013, WorldCIS-2013 and WCST-2013 Steering Committee Chair
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Keynote Speakers
WCST-2013: Keynote Speaker 1

Dr. Tyson T. Brooks is a Co-Director for the Wireless Grid Innovation Testbed (WiGiT) at Syracuse University and works for the U.S. Department of Defense (DoD). Dr Brooks's professional experience is in the design, development and production of a broad range of information systems services, as well as leading the effort to develop secure information system architecture's for the federal government. Dr Brooks is responsible for developing and managing a comprehensive suite of analytical and technical services designed to enable government and commercial business leaders to achieve improved mission performance through secure information system architecture's. His research interest are in the fields of wireless grid Edgeware architectures, information architecture security, cybersecurity and enterprise/system architecture. As a published author, Dr Brooks is also a member of IEEE, ISSA, PMI and is an associate editor for the Journal of Enterprise Architecture, the International Journal of Cloud Computing and Services Science (IJ-CLOSER) and the International Journal of Information and Network Security (IJINS). Dr Brooks holds a doctorate in Information Management and a CAS in Information Security Management from Syracuse University, a master's degree in Information and Telecommunications Systems from Johns Hopkins University, a master's degree in Business Administration from Thomas More College, and a bachelor's degree in Business Administration/Management from Kentucky State University. Dr Brooks also received a Certification in Enterprise Architecture (CEA) from Carnegie Mellon University's Institute for Software Research International (ISRI) and a Project Management Professional (PMP) certification from the Project Management Institute.

Title: Blurred Nets: Disruption and the Risk to Future ‘Internet of Things’ (IoT) Architectures

Abstract: The Internet of Things (IoT) is an integrated part of the future Internet with self-configuring capabilities based on interoperable communication protocols where physical and virtual ‘things/objects’ have identities, physical attributes and are seamlessly integrated into the information network. This keynote will address three key themes in this IoT evolution, each defining stages in the evolution of the Internet over the next decade. Over the next few years, the importance of collaboratory participation nets will further increase active creation and passive consumption. By 2015, immersive nets become predominant, integration local tags, wireless networks and smart environment’s offer a cloud of information accessible and editable both remotely and in-person. After 2017, metaverse nets will take this augmented world and add connections with virtual environments. Although innovative, the risk and disruption to these new architectures will present challenges to the IoT Cyber domain needing to address the very large numbers of ‘things/objects’ handing data in this new global information space.
Dr. Yoon Seok Chang is a Professor at the School of Air Transport and Logistics and Director of Ubiquitous Technology Application Research Center, at Korea Aerospace University. He served as Dean of Information System and Service at Korea Aerospace University and was a visiting scholar at the department of computer science, Caltech, USA. Prior to joining Korea Aerospace University, he was a visiting professor of KAIST, a senior research associate of Cambridge University, a senior application engineer of i2 and a visiting professor of Arizona State University. He finished his PhD at Imperial College London, UK, 1997 majoring manufacturing system at the department of Mechanical Engineering. He was the editor of the Evolution of Supply Chain Management, published (Kluwer Academic Publisher) and is currently serving as an editorial board of members of Human Factors and Ergonomics in Manufacturing and Service Industries (Wiley, USA). His research interests are ICT applications in logistics area and smart machine design.
Professor N.J. Hewitt, BSc DPhil CEng CPhys MInstP MInstR MEI is Director, Centre for Sustainable Technologies, Editor in Chief, International Journal of Ambient Energy and Head of Research Graduate School, Faculty of Art, Design and Built Environment of the University of Ulster. Ulster is a university with a national and international reputation for excellence, innovation and regional engagement. Our core business activities are teaching and learning, widening access to education, research and innovation and technology and knowledge transfer and has a positive impact on the economy and community in Northern Ireland and employ over 3000 staff with an annual turnover of more than £200 million. Professor Hewitt is an expert in Refrigeration, Air-Conditioning, Heat Pumps and energy storage with considerable capability in energy market modelling and energy system modelling and bioenergy. He has attracted over £12M of EPSRC, EU and other international research funding and has over 100 journal publications. The Centre for Sustainable Technologies with a staff of 30 academics, researchers etc. has considerable laboratory facilities for the investigation of novel solar energy technologies, biomass gasification, bio-oils from seeds and nuts, advanced glazing systems, thermodynamic cycles and engines, thermal energy storage, energy market modelling and energy system generation including carbon capture and storage.

**Title:** Energy Storage and Demand Side Management Challenges in Managing Renewable Energy Integration

**Abstract:** Energy storage and demand side management represent methods of integrating non-dispatchable renewable energy such as wind onto existing electricity networks. Energy storage at a utility scale through pumped storage is widely used in the UK but there is a need to explore alternative technologies such as compressed air energy storage. In addition, different scales of distributed energy storage may make a valuable contribution, namely site integrated storage that enables a local non-dispatchable renewable energy generator to become dispatchable. Finally demand-side management will address for example a major energy user, namely household heating. However decreases in individual unit scale lead to greater information needs and flows to ensure adequate control within local electricity network constraints. An overall integration of these approaches through market modelling will determine likely economic benefits and this approach will be explored through the recently started Interreg IVA SPIRE (Storage Platform for the Integration of Renewable Energy) project and an outline of this project will be given.
Charles A. Shoniregun is a Professor of Applied Internet Security and Information Systems, Founder of Infonomics Society. He is an invited speaker to NATO, guest speaker to many universities in the UK and abroad on issues relating to his research and consultancy area, and have several times won the IEEE Certificate of Appreciation. In 2008, he was invited speaker at the Joint C2 Capabilities Conference organised for the senior military and US government personnel in Washington DC. His research interests are in the fields of Internet security, Cyber Terrorism, risks assessment of technology-enabled information, electronic and mobile commerce (emC), second-life applications, third-stream activities, telecommunications and applied information systems. He is a committee member of the Harvard Research Consortium and Global Seminars (Harvard University), Editor-in-Chief of Eight International Journals, Author, Co-author, Adjunct and Distinguished Professor in "Applied Internet Security and Information Systems", External Assessor to many Universities, Consultant to private and public sectors.

**Title:** Writing a Sustainable Research Paper

**Abstract:** The idea of writing a sustainable research paper or developing a topic of research interest that can lead to a PhD / Doctorate degree or proposal is always an endless thinking of where, when, why, what and who. Therefore, becoming an experienced researcher and writer in any field or discipline takes a great deal of practice. This Keynote Lecture will highlights the possible solutions in response to the lack of competence demonstrated by young researchers and PhD / Doctorate students, and the understanding of what contributes to knowledge gap.
Dr John Littlewood has studied, practised and lectured in the built environment since 1986 in both craft and professional roles; with a particular focus on architectural technology; sustainable housing design and construction; assessing and monitoring the thermal performance of dwellings during the construction process with in-construction testing (ICT) and post occupancy evaluation. John’s PhD was entitled ‘A study of the design and thermal performance of two-storey earth sheltered houses for the UK climate’, which he completed in 2001. The majority of John’s consultancy and research projects are and have been undertaken in collaboration with industry, mainly housing associations, contractors and design teams and funded directly by industry, the EU or UK research council grants in excess of £1 Million; with over 60 publications. Since 2009, much of John’s research and enterprise has centred on developing methodologies for assessing the environmental performance during the construction process and post construction of new and existing dwellings and also investigating end user energy demand and user behaviour in single dwellings or multi-storey apartment buildings. John has been practising as a sustainability consultant and building performance evaluator with a number of housing associations and also BDP, since 2007. John foundered and has led the Ecological Built Environment Research & Enterprise group (EBERE) at Cardiff Metropolitan University, in Cardiff School of Art and Design since 2009. John also co-foundered the Professional Doctorate: Ecological Building Practices (DEBP) in 2009. John is currently supervising seven DEBP students from the UK, South Africa and Canada and numerous PhD students in low carbon housing design; integration of earth tubes for healthy ventilation of non domestic buildings; rammed earth construction for house construction; assessment of retrofitted external wall insulation on thermal performance. John has been involved with the International Conference series on Sustainability in Energy and Buildings (SEB) since 2010 as Chair of various conference tracks and in 2014 he is Chair of SEB’14, being hosted in Cardiff.
Sessions
Session 1: Sustainable Energy Technologies

The Research of Reactive Power Control Strategy for Grid-connected Photovoltaic Plants
(Authors: Lin Zhou, Yang Chao)

Experimentally diagnosing the shading impact on the power performance of a PV system in Hong Kong
(Authors: Jinqing Peng, Lin Lu, Hongxing Yang, KM Ho, Peter Law)

Utility-Scale Solar Energy Planning for Egypt
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(Authors: I. Garrido, A.J. Garrido, M. Alberdi, M. Amundarain, M. de la Sen)
The Research of Reactive Power Control Strategy for Grid-connected Photovoltaic Plants

Lin ZHOU
Department of Electrical Engineering
Chongqing University
Chongqing, China
zhoulin@cqu.edu.cn

Yang CHAO
Department of Electrical Engineering
Chongqing University
Chongqing, China
c729048086@163.com

Abstract—Grid-connected photovoltaic (PV) plants should have independent control of reactive power to provide reactive power support to the grid. The study analyzes the impact the varying output of the active and reactive power of photovoltaic plants have on network voltage, and derives the relationship between active and reactive power change and voltage change amount. A reactive power control strategy of for grid-connected PV plants is proposed. It shows that voltage fluctuation at point of common coupling (PCC) caused by PV plants will be suppressed. The overall control strategy scheme diagram of active power and reactive power of PV plants is structured in stationary frame, avoiding the complex aspects of the phase-locked loop (PLL) and decoupling. The control method is analyzed under the adverse grid conditions, the adverse impact on the grid current caused by the outlets voltage distortion and imbalance is suppressed. The constraint condition of the reactive power of the inverter is analyzed and deduced. Simulation results prove the validity of the theoretical analysis, demonstrating its excellent performance.

Keywords-grid-connected PV plant; independent control of reactive power; stationary reference frame; voltage fluctuation; reactive power constraint

I. INTRODUCTION

With the cost decreasing, large-scale grid-connected PV plants have gained international attention recently. However, as the scale of the PV plants expands, the effect on the grid is gradually emerging. PV plants in the future can take control of active and reactive power independently, suppress low frequency oscillation, with low voltage ride through ability, provide emergency reactive support, et al. To address the adverse effects on the grid caused by PV plants, it is necessary to make study on key technology of PV connected to the grid.

PV plants should be equipped with reactive power-voltage control ability. The reactive power and voltage regulation methods include adjusting the reactive power output by PV plants or other reactive power compensation equipment, and the step-up transformer ratio. PV plants should make full use of the reactive adjustment ability of the inverter to regulate reactive power and voltage [1].

When PV plants connected to the grid, the voltage at PCC may be out of limit and the voltage fluctuates as the PV plants output changes, which can be solved by adjusting the reactive power of the PV plants. When the PCC voltage dropped caused by transient faults, the PV system can adjust the reactive power to provide voltage support. PV plants can also compensate the reactive power of transmission lines, enhancing their transmission capacity. All above is the significance of the reactive power independent control of PV plants, and few studies is conducted on reactive control of PV plants while study mainly focused on the unit power factor operation [2]. Unified control of the PV grid connected generation and reactive power compensation is researched [3] - [6], which detects and compensates the load reactive power but not suitable for the reactive independent control of PV plants. Reactive power can be controlled independently of PV system based on voltage sensitivity or constant power factor in distribution generation system [7] - [8].

In this paper, a novel independent reactive power control strategy of three-phase grid-connected PV inverters without PLL is proposed. The strategy is based on two-phase stationary-frame with the positive-sequence voltage detector. This paper is organized as follows. First, the impact on the grid caused by varying output active and reactive power of PV plants is analyzed, and the expression between of active variation, reactive variation and voltage variation is got. Second, reactive power control strategy based on the stationary reference frame and the positive-sequence voltage detector to three-phase three-wire systems are presented. Next, the constraint conditions of the reactive power of the inverter are analyzed. Finally, the theoretical study is validated through simulation results.

II. OVERVIEW OF THE PV PLANTS

PV plants generally adopt multi-machine parallel topology, which can be divided into the mode of multiple independent operating and shared DC bus. In the mode of multiple independent operating, PV array and its inverter input are independent from each other; inverters are connected to the grid in parallel. In this mode, inverter systems work independent, simple to control, but it cannot guarantee the match between a single inverter and the entire system to the maximum efficiency. In the shared DC bus mode, DC output of the PV array is in parallel, and inverter output is connected to the grid in parallel. Centralized group control technology can be adopted to control the inverter group. System efficiency can be scheduled, which helps optimize the configuration of the...
system, improving the overall efficiency, but it is complex to control.

Large-scale PV plants are mostly concentrated in the desert and semi-desert areas, rich in sunshine. Since the local load is small, the electricity of PV systems needs long-distance transportation. Line impedance [9] cannot be ignored. PV plants have no rotating inertia. Active power presents step-type changes, causing greater impact on the voltage at PCC. The paper, focusing on PV systems with multiple independent operating modes, mainly researches the effect of PV systems on the grid voltage stability and independent reactive control strategy of a single PV inverter. The topology is shown in Fig. 1.

Figure 1. Schematic diagram of grid-connected photovoltaic system

III. ACTIVE AND REACTIVE POWER CONTROL OF PV SYSTEM

A. Effects of PV Systems on Voltage Regulation

The Thevenin equivalent circuit at PV systems connected point is shown in Fig. 2. The influence on voltage at the PCC can be divided into three cases: 1) the voltage rise when PV system connected to the grid; 2) voltage fluctuations caused by varying output of PV system; 3) voltage drops when the grid-fault.

When the active and reactive power output of the PV system varies, the voltage at PCC can be calculated, as shown in (1).

\[
\Delta u = \left( R_s + jX_s \right) \left( \Delta I_r + j\Delta I_q \right) \\
= |Z_s| \left( \cos \theta + j \sin \theta \right) \Delta I \left( \cos \theta + j \sin \theta \right) \\
= \frac{\Delta S_p}{S_t} \left[ \cos (\theta + \phi) + j \sin (\theta + \phi) \right]
\]

Where \( \Delta S_p \), \( U \), \( S_t \), \( \phi \), \( \theta \), \( \Delta I_r \), and \( \Delta I_q \) denote, respectively, PV system power changes, rated voltage value, short circuit capacity, the equivalent impedance angle, power factor angle for PV system, active and reactive current changes. Known from (1), the trajectory of the voltage changes is round. Vector diagram for voltage change caused by PV generation is shown in Fig. 3.

Figure 3. Vector analysis diagram for voltage change caused by PV system

The inverter works on four-quadrant operations. The grid voltage can be stabilized by regulating active and reactive power of the PV inverter. When \( \Delta u \) moves on the upper circle of the \( r \) axis, PV active power output increases and the system should reduce the reactive power output; when \( \Delta u \) moves on the lower circle of the \( r \) axis, PV active power output decreases, and the system should increase reactive power. To achieve the above objectives, PV system should take independently control of reactive power.

The angle \( \delta \) changes quite small when voltage at PCC fluctuates as in Fig. 3. If \( |u| = |u'| = |u''| \), we can have

\[
\frac{\Delta I_r}{\Delta I_p} = \frac{R_s}{X_s} \\
\frac{\Delta P}{\Delta Q} = -\frac{R_s}{X_s}
\]

PV systems reactive power control strategy can be determined by (3).

B. Reactive power control strategy of PV system

In order to achieve the goal of active and reactive power independent control, this paper establishes the control scheme diagram for a single grid-connected PV unit, including the active control loop, reactive independent control loop and the current control loop as shown in Fig. 4.

- Active and reactive power control strategy

A reactive power control strategy based on the \( \alpha-\beta \) two-phase stationary frame is proposed in this paper. Zero steady-state error can be tracked by using a quasi-PR controller [10]. Since active and reactive current are not coupling, the active and reactive reference value of the current as \( i_{\alpha}^* \) and \( i_{\beta}^* \) will be got by taking control of the active and reactive power independently, then \( i_{\alpha}^* \) and \( i_{\beta}^* \) under stationary frame is got.
The control of active power can be achieved by taking control of DC bus voltage, and it is shown in Fig. 4. The transfer function from $i_{dc}^*$ to $v_{dc}$ is shown as

$$G_e(s) = \frac{1}{sC}$$  

A PI controller with a low-pass filter [11] is used for inhibiting the low-order harmonics of injected current. Consider the loss of the inverter, according to system power conservation, we can have

$$P = v_{dc} \cdot i_{dc} = e_d \cdot i_{sd}$$  

(5)

The control diagram of reactive power loop is shown in Fig. 4. $e_d$ in (5) is the straight axis component of three-phase grid voltage transformed by rotated coordinate transformation. In this paper $e_d$ can be determined as (6).

$$e_d = \sqrt{(v_{sa})^2 + (v_{sb})^2}$$  

(6)

The purpose of modeling and control of reactive power loop is to realize independent control of reactive power and get the injected reactive reference current. Reactive power can quickly and accurately track the change of the given reactive regulation. Reactive power reference value $Q^*$ is determined by $Q_s + \Delta Q$, and $\Delta Q$ is obtained from (3) by being detected the fluctuations of active power. $Q_s$ is used to compensate the reactive power of transmission lines at night; Reactive power loop can adopt a PI controller with a low-pass filter. The closed-loop control diagram is shown in Fig. 5.

$$Q' = \frac{\tau_0 s + 1}{\tau_0 s} \frac{1}{\tau_0 s + 1} i_q \rightarrow e_q$$  

Figure 5. Control diagram of reactive power-loop

The open-loop transfer function of reactive power control loop is obtained from Fig. 5.

$$T_q(s) = -e_d \frac{\tau_0 s + 1}{\tau_0 s} \frac{1}{\tau_0 s + 1}$$  

(7)

The controller parameters can be designed with dynamic indicators of PV system, $\tau_0$ value can be set with the cut-off frequency of low-pass filter in the controller.

- Control strategy of the grid in adverse operation

The synchronization of PV system to grid is affected when grid is in distortion and unbalance operating conditions, which will cause injected current distorted. Always the inverter synchronized to the grid generally by the PLL, but when the three-phase grid voltage is distorted or unbalance, especially the voltage wave appears several zero-crossing point, the PLL will be unlocked, affecting the normal work of the inverter. In this paper, the principle of positive sequence extraction [12] is adopted to obtain the positive sequence components of grid voltage, which are $v_{sa}^{+}$ and $v_{sb}^{+}$ under the two-phase stationary frame. The sine and cosine in the matrix $C_{dq/ab}$ can be replaced as

$$\sin(\alpha + \phi) = \frac{v_{sa}^{+}}{\sqrt{(v_{sa}^{+})^2 + (v_{sb}^{+})^2}}$$  

$$\cos(\alpha + \phi) = \frac{v_{sb}^{+}}{\sqrt{(v_{sa}^{+})^2 + (v_{sb}^{+})^2}}$$  

(8)

In case of the grid voltage is distorted and unbalance, negative sequences and harmonic components will appear in the grid voltage, causing negative sequences and harmonic components in the grid current. Voltage negative sequence and harmonic components can be expressed as (9).

$$v_{sa}^{-} = v_{sa} - v_{sa}^{+}$$  

$$v_{sb}^{-} = v_{sb} - v_{sb}^{+}$$  

(9)

$v_{sa}^{-}$ and $v_{sb}^{-}$ are controlled feed-forward to suppress the influence of grid disturbances on injected current, eliminating the negative sequence and unbalanced components of the current caused by the grid distortion and unbalance. The feed-forward control scheme diagram is shown in Fig. 4. $K_{pum}$ is the inverter gain, and $K_{pum} = V_d/2$. 

---

Figure 4. Active and reactive power control strategy in stationary frame
Equ. (6) can be replaced by (10)

\[ e_d = \sqrt{(v_{im}^*)^2 + (v_{im})^2} \]  

(10)

When the grid voltage is unbalance, the DC bus voltage has secondary fluctuations, causing the secondary fluctuations in instantaneous active and reactive power, leading to 3rd harmonics in injected current. The second notch filter is introduced to the active and reactive power control loop to suppress the harmonics of the active and reactive power control loop output, thus the 3rd harmonics of the grid current is inhibited. The transfer function of second notch filter is

\[ f(s) = \frac{s^2 + \alpha_0^2}{s^2 + \alpha_k Q_0 + \alpha_0^2} \]  

(11)

Where \( \alpha_0 = 2 \times 100\pi \) is the filtered signal frequency, \( Q_0 \) is the quality factor.

C. Reactive constraints of the inverter

From the analysis above, the reactive power can be regulated according to active power changes. Urgent reactive power support is needed in case of emergency situation. Capability of the inverter for producing reactive power is influenced by the following three aspects. Firstly, when the active power output is certain, it will be restricted by the inverter capacity [13]. Secondly, it will be restricted by the transmission lines. Thirdly, when the capacity of the inverter is sufficiently large, it is limited by the DC bus voltage. If reactive power exceeds a certain limit, the anti-parallel freewheeling diode of the three-phase inverter bridge is forward conducted when none of the power switch is conducted, therefore, the current cannot be tracked accurately, resulting in the output current distorted, and active and reactive power fluctuations. Reactive power constraints of the inverter DC bus voltage limit is got in this section.

Fig. 6 shows the phase-voltage vector diagram of the inverter. As for phase A, Where \( I_a, V_{sa}, V_{ra} \) and \( \phi \) denotes respectively, output current, output voltage of the inverter of phase A, voltage of the grid, and the power factor angle.

\[ V_{ra} = \left[ V_{sa} + \omega L \frac{Q}{3V_{sa}} \right] + \left[ \omega L \frac{P}{3V_{sa}} \right] \]  

(12)

And

\[ P = 3 V_{sa} I_a \cos \phi \]

\[ Q = 3 V_{sa} I_a \sin \phi \]

According to SPWM modulation scheme, to exclude low-order harmonics in phase-to-phase voltage of the inverter, DC voltage must be \( \sqrt{6} \) times larger than RMS output phase voltage. Reactive power capacity constraints is

\[ Q < \frac{3V_{sa}^2}{2\omega L} \]  

(13)

The inverter capacity constraints is

\[ Q < \sqrt{S^2 - P^2} \]  

(14)

From (13-14), when the grid in case of emergent situation requires reactive power support by PV systems, active power should be reduced.

IV. SIMULATION RESULTS

In order to verify the correctness of the theoretical analysis, the simulation model of PV plants connected to the 10 kV transmission network is built in MatLab-simulink software. scheme diagram is shown in Fig.7, and simulation parameters is shown in Table I

The active and reactive reference current and grid-connected current waveforms are shown in Fig.8. The grid voltage is unbalanced and contains 5 and 7 order harmonics. Before 0.2s, active and reactive reference current has secondary ripple, and the injected current waveform is distorted without distortion and unbalance control strategy. At 0.2s time, grid distortion and unbalance control strategy is applied, the secondary harmonic in \( i_d^* \) and \( i_q^* \) is eliminated, and the injected current \( i_s \) waveform is sinusoidal. As is shown in Fig.8 (c), the grid current THD is 0.44% by FFT analysis. The simulation results show that the strategy of grid distortion and unbalance significantly improve the grid current quality.

### TABLE I. SYSTEM PARAMETERS

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated output power</td>
<td>( P_m = 100\text{KW} )</td>
</tr>
<tr>
<td>Switching frequency</td>
<td>( f_{sw} = 4.8\text{kHz} )</td>
</tr>
<tr>
<td>DC-link voltage</td>
<td>( V_d = 800\text{V} )</td>
</tr>
<tr>
<td>Filter inductance</td>
<td>( L = 3\text{mH} )</td>
</tr>
<tr>
<td>Grid frequency</td>
<td>( f_g = 50\text{Hz} )</td>
</tr>
<tr>
<td>Transformer ratio</td>
<td>( K = 0.4\text{kV}/10\text{kV} )</td>
</tr>
<tr>
<td>Nominal grid voltage(RMS)</td>
<td>( u_g = 10\text{kV} )</td>
</tr>
<tr>
<td>Grid R/X ratio</td>
<td>0.28</td>
</tr>
</tbody>
</table>

The active and reactive reference current and grid-connected current waveforms are shown in Fig.8. The grid voltage is unbalanced and contains 5 and 7 order harmonics. Before 0.2s, active and reactive reference current has secondary ripple, and the injected current waveform is distorted without distortion and unbalance control strategy. At 0.2s time, grid distortion and unbalance control strategy is applied, the secondary harmonic in \( i_d^* \) and \( i_q^* \) is eliminated, and the injected current \( i_s \) waveform is sinusoidal. As is shown in Fig.8 (c), the grid current THD is 0.44% by FFT analysis. The simulation results show that the strategy of grid distortion and unbalance significantly improve the grid current quality.
Fig. 8. Active and reactive reference current and grid-connected current waveforms by grid voltage distorted and unbalance Control strategy (a) Active and reactive reference current and grid-connected current waveforms, (b) partial enlarged for 1, (c) Partial enlarged for 2. (i_sdr) active reference current, (i_sqr) reactive reference current (i_sa, i_ssb, i_ssc) injected current for phase A, B, C.

Fig. 9 shows the positive-sequence phase voltage and injected current waveform when reactive power of PV plants changes. During 0.2s to 0.25s, the PV plants generates 100 kW active power and 40kvar reactive power, then v_sb is ahead of i_sb. During 0.25s to 0.3s, the PV plants generates 100 kW active power without reactive power, then v_sb is co-frequency and co-phase to i_sb, that PV plants is in unity power factor operation; During 0.3s to 0.35s, the bus voltage lags the injected current when reactive power output is -40kvar.

To verify the feasibility of reactive power independent control strategy and its function of keeping the PCC voltage steady, simulation of the effect of the PV plants have on the PCC voltage is studied. Active power is increased between 8h and 14h, and reduced between 14h and 20h. Fig. 10 (a) shows the voltage at PCC fluctuates as the active power output of PV plants changes when the system is operating in unity power factor operation. Fig. 10 (b) shows, during the day, When P changes, we can regulate Q of the PV plants that the PCC voltage can keep steady at 1.037p.u. Therefore the voltage can stay almost constant by regulating Q. The simulation results show that the reactive power control strategy of PV plants proposed in this paper can effectively suppress the grid voltage fluctuations.

Fig. 11 is the simulation result of the reactive power constraint. Calculate parameters from Table I, when active power of PV plants is 100 kW and reactive power constraint is 45kvar, the inverter works normally. Injected current begins to distort when reactive power is greater than 45kvar. The injected current distortion is bigger and bigger by increasing reactive power. In the first 0.4s, the PV plant reactive power output is 45kvar, and the grid current is sinusoidal without distortion; between 0.4s and 0.6s, the reactive output is increased to 65kvar, and the current waveform begins to distortion, active...
and reactive power contains lower order harmonics; between 0.6s and 0.8s, reactive power output increases to 75kvar, and the current waveform distorts seriously, active power and reactive power contains large amounts of low-order harmonics shown in Fig.11. The simulation results prove the theoretical correctness of reactive capacity constraints.

ACKNOWLEDGMENT

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Experimentally diagnosing the shading impact on the power performance of a PV system in Hong Kong

Jinqing Peng, Lin Lu*, Hongxing Yang
Department of Building Services Engineering
The Hong Kong Polytechnic University
Hong Kong, China
Email: vivien.lu@polyu.edu.hk

KM HO, Peter Law
Water Supplies Department (WSD)
Hong Kong Special Administrative Region, Hong Kong, China

Abstract—This paper presents an experimental diagnosis on the power performance of a PV system in Hong Kong. The annual solar radiation received by the PV modules was simulated based on the recorded horizontal solar radiation. The theoretical annual energy output of this PV system was about 11,702 kWh/yr, which was higher than the actual energy output by 24.5%. In order to find out the reasons of the energy loss, an on-site inspection and testing was conducted. The shading and aging problems were found in the process of visual inspection. The shading problem can be further subdivided into edge-shading, pillar-shading and nameplate shading. To further understand and quantify the impact of different types of shadings on the power output performance, the I-V curves of a PV module were tested under different solar radiation. The testing results showed that the impact of different types of shadings on the power performance varied with the Sun position, solar radiation as well as the time. In general, the edge-shading effect reduced the energy output of PV system by 11%-15%, the pillar-shading effect reduced the energy output by 15%-19%, and both effects of edge-shading and pillar-shading reduced the energy output of PV system by 18%-35%. Thus, the main reason that resulted in the energy loss of this PV system was attributed to the shading impact. If the edge-shading and pillar-shading problems are solved, the annual energy output of the PV system could increase about 20%-24%.

Keywords-component; Solar energy; PV system; shading impact; energy loss

I. INTRODUCTION

The photovoltaic (PV) system diagnosed in this study is located in water treatment works in Hong Kong. This PV system was built in 2007. It is facing southwest and with a tilted angle of about 20°. The total PV installation capacity is about 10.6 kWp, comprising by 60 pieces of mono-Si PV modules. Recently, the customers reflected that the PV system operated under low energy conversion efficiency state, thus an on-site testing and diagnosing work has been done to find out the problems. The PV arrays of this PV system are shown in Fig. 1. These PV modules purchased from three different manufacturers, viz. Suntech, Shell and Solgro, and were divided into 6 PV arrays. The specification parameters of the PV modules are listed in Table 1. In each array, 10 pieces of the same modules were connected in series. Every two arrays, whose PV modules came from the same manufacturer, were connected in parallel before connected into an Inverter. Three SMC 6000A inverters manufactured by SMA were used in this system to inverter the DC power to AC power. The specification parameters of the inverters are listed in Table 2. The schematic diagram of the PV system is presented in Fig. 2. From the specifications of the PV modules and Inverters, there is no mismatching problem between the PV modules and inverters.

Figure 1. The PV arrays of the PV system (only half arrays are shown in this photo)

Figure 2. Schematic diagram of the PV system
TABLE I. SPECIFICATION PARAMETERS OF THE MONO-SI PV MODULES

<table>
<thead>
<tr>
<th>Parameters/manufacturers</th>
<th>Shell</th>
<th>Suntech</th>
<th>Solgro</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Power at STC ($P_{max}$)</td>
<td>175 W</td>
<td>175 W</td>
<td>180 W</td>
</tr>
<tr>
<td>Optimum Operating Voltage ($V_{mp}$)</td>
<td>35.4V</td>
<td>35.2V</td>
<td>35.2V</td>
</tr>
<tr>
<td>Optimum Operating Current ($I_{mp}$)</td>
<td>4.95A</td>
<td>4.95A</td>
<td>5.11A</td>
</tr>
<tr>
<td>Open Circuit Voltage ($V_{oc}$)</td>
<td>44.6V</td>
<td>44.2V</td>
<td>43.6V</td>
</tr>
<tr>
<td>Short Circuit Current ($I_{sc}$)</td>
<td>5.43A</td>
<td>5.2A</td>
<td>5.5A</td>
</tr>
<tr>
<td>Module Efficiency</td>
<td>13.3%</td>
<td>13.7%</td>
<td>14%</td>
</tr>
<tr>
<td>No. of PV modules/PV arrays</td>
<td>20/2</td>
<td>20/2</td>
<td>20/2</td>
</tr>
<tr>
<td>Dimensions</td>
<td>1622 × 814 × 40mm</td>
<td>1580 × 808 × 35mm</td>
<td>1580 × 808 × 35mm</td>
</tr>
</tbody>
</table>

TABLE II. SPECIFICATION PARAMETERS OF THE SMC 6000A INVERTER

<table>
<thead>
<tr>
<th>Parameters</th>
<th>values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. operating voltage (DC)</td>
<td>600V</td>
</tr>
<tr>
<td>Operating voltage range (DC)</td>
<td>213-600V</td>
</tr>
<tr>
<td>Nominal operating voltage (DC)</td>
<td>270V</td>
</tr>
<tr>
<td>Max. input current (DC)</td>
<td>26A</td>
</tr>
<tr>
<td>Nominal operating voltage (AC)</td>
<td>230V</td>
</tr>
<tr>
<td>Nominal operating frequency (AC)</td>
<td>50/60Hz</td>
</tr>
<tr>
<td>Nominal output power (AC)</td>
<td>6000W</td>
</tr>
<tr>
<td>Max. output power (AC)</td>
<td>6000W</td>
</tr>
<tr>
<td>Max. output current (AC)</td>
<td>26A</td>
</tr>
</tbody>
</table>

II. ANALYZING OF ENERGY LOSS

The theoretical annual energy output of this PV system can be calculated by (1):

$$E_{theoretical} = A_{act} \times G \times \eta_{stc} \times \lambda$$  

(1)

Where, $E_{theoretical}$ is the theoretical annual energy output, (kWh); $A_{act}$ is the active area of the all PV modules, (m$^2$), the total active area is about 77.4 m$^2$; $\eta_{stc}$ is the PV modules’ energy conversion efficiency under standard test conditions (STC). According to the specifications of PV manufacturers, the energy conversion efficiency of the above mentioned three kinds of PV modules are respectively 13.3% for Schell, 13.7% for Suntech and 14% for Solgro. $\lambda$ is the performance ratio of PV system. This ratio considers all losses from converting solar energy into direct current electricity and then inverting the direct current into alternating current electricity. In this study, $\lambda$ is assumed to be 0.75 [1]. $G$ is the annual total solar radiation received by the PV modules, (kWh/yr.) The horizontal hourly solar radiation was recorded by a sun tracker with two pyranometers in the Hong Kong Polytechnic University. However, only horizontal total and diffuse solar radiations can be recorded by this equipment. Thus, it is necessary to transfer the horizontal solar radiation into tilted surface. The hourly total solar radiation incidence on a tilted surface, $G_{tt}$, can be expressed as follows:

$$G_{tt} = G_{bh} + G_{dh} + G_r$$  

(2)

Where, $G_{bh}$ is the beam hourly solar radiation incidence on a tilted surface, W/m$^2$; $G_{dh}$ is the hourly diffuse solar radiation incidence on a tilted surface, W/m$^2$; and $G_r$ is the hourly reflected solar radiation, W/m$^2$. $G_{bh}$ and $G_{dh}$ can be given by the following equations, respectively [2].

$$G_{bh} = \frac{G_{hb} \times R_{bh}}{\cos \theta} \cos \theta$$  

(3)

$$G_{dh} = \frac{\rho_o}{2} \cdot G_{th} \cdot (1 - \cos \beta)$$  

(4)

Where, $G_{th}$ is the beam radiation incidence on the horizontal surface, it can be extracted from the total horizontal radiation of $G_{th}$ (measured by the suntracker); $\theta$ is the angle of incidence; $\beta$ is the slope angle of PV modules; $\theta_z$ is the zenith angle; $\rho_o$ is the ground reflectance.

The Perez model was adopted to simulate the diffuse solar radiation incidence on the tilted surface because this model can provide high accuracy results for PV modules with a lower tilted angle. In the Perez Model, the diffuse solar radiation incidence on a tilted surface can be calculated by (5) [3-4]:

$$G_{dh} = G_{dh} \cdot \left[1 - F_i \cdot \left(1 + \frac{\cos \beta}{2}\right) + F_i \cdot \frac{a}{b} + F_c \cdot \sin \beta\right]$$  

(5)

Where, $G_{dh}$ is the diffuse solar radiation incidence on the horizontal surface, it can be extracted from the total horizontal solar radiation, $G_{th}$.

In order to simulate the annual solar radiation received by the PV modules, a FORTRAN program was developed based on the above mathematic models. The average annual solar radiation received by the PV modules was calculated to be about 1380kWh, which is a little less than the highest solar radiation received by the optimum orientation and tilted angle. Substituting the solar radiation $G$, energy conversion efficiency $\eta_{stc}$, performance ratio $\lambda$, and active area $A_{act}$ into the (1), the theoretical energy output was calculated to be 11700 kWh/year. The actual energy output of this PV system was recorded from June 2007 to June 2013. Fig. 3 presents the monthly energy output of this PV system. Fig. 4 shows the annual energy output from 2008 to 2012. It is found that the
actual average annual energy output was 9396 kWh, which is lower than the theoretical annual energy output by 24.5%. Thus the purpose of this study is to find out the reasons causing the 24.5% energy loss.

III. INSPECTING AND TESTING

A. Visual inspection

Three problems were found in the process of visual inspection. First of all, two kinds of permanent shading were found to affect the power output performance of PV system, viz. edge-shading caused by the U-bar and the pillar-shading caused by the pillars in front of the PV modules. Fig. 5 shows the edge-shading caused by the U-bar. Almost all PV modules, except the PV modules manufactured by Shell, are affected by the edge-shading. Fig. 6 shows the comparison of edge-shading effect on Shell’s PV module and Suntech’s PV module. It can be seen that there is almost no edge-shading for the Shell’s PV module due to its longer length (1622 mm) than the other two types of PV modules. And this is the reason why the inverter connected to the PV modules made by Shell has higher average electricity production rate. The hourly average electricity production rate of the Shell’s PV arrays is about 0.81 kWh, while they are 0.65 and 0.71 kWh for the PV arrays made by Solgro and Suntech, respectively. Thus, from the average electricity production rate, it is found that only the edge-shading could reduce the energy output of the PV modules by about 12%.

Fig. 7 shows the pillar-shading caused by the pillars in front of the PV modules. Fig. 7 shows the pillar-shading caused by the pillars in front of the PV modules. It can be seen that almost all the PV modules in the first row were shaded by the pillars. Secondly, temporary shading caused by a nameplate was found and showed in Fig. 8. This kind of shading may cause the energy output performance of the PV array reducing significantly. Last but not least, it was found that there are some quality problems for the PV modules made by Solgro. Firstly, a few pieces of multi-Si solar cells exist in the mono-Si PV panels, as
shown in Fig. 9. Secondly, as shown in Fig. 10, the aging problem is very serious and the EVA of the PV modules has become yellow. Thus it can be seen that the PV modules made by Solgro have quality problems on the solar cells and EVA. And this is the reason why the inverter connected to the PV modules made by Solgro has the lowest average electricity production rate of 0.65 kWh, even its rated power is higher than the PV modules made by the other two manufacturers.

B. I-V measuring and power testing

In order to further understand and quantify the impact of different types of shadings on the power output performance, a PV module made by Suntech was disassembled for conducting I-V testing.

Fig. 11 presents the I-V testing results under different shading conditions at 12:51-12:56. It can be seen that the maximum power is about 146W without shading, but it was reduced to 126W affected by edge-shading, to 118W affected by pillar-shading, and further reduced to 110W affected by both edge-shading and pillar-shading. The edge-shading resulted in the reduction of open circuit voltage and short circuit current, and reduced the power output by about 14%. The pillar-shading caused the reduction of the maximum power of PV module and reduced the power output by about 19%. Both the effects of edge-shading and pillar-shading reduced the power output by about 25%.

Fig. 12 presents the I-V testing results under different shading conditions at 14:11-14:23. It can be seen that the maximum power is about 122W without shading, but it was reduced to 103W affected by edge-shading, to 102W affected by pillar-shading, and further reduced to 93W affected by both
edge-shading and pillar-shading. The edge-shading effect reduced the power output by about 15%. The pillar-shading effect caused the reduction of the maximum power of PV module and reduced the power output by about 16%. Both the effects of edge-shading and pillar-shading reduced the power output by about 24%.

Fig. 13 presents the I-V testing results under different shading conditions at 16:11-16:13. It can be seen that the maximum power is about 90W without shading, but it was reduced to 80W affected by edge-shading, to 73W affected by pillar-shading, and further reduced to 59W affected by both edge-shading and pillar-shading. The edge-shading effect reduced the power output by about 11.1%. The pillar-shading effect caused the reduction of the maximum power of PV module and reduced the power output by about 19%. Both the effects of edge-shading and pillar-shading reduced the power output by about 35%.

IV. DISCUSSIONS AND CONCLUSIONS

Based on the above testing results, it can be found that the impact of different types of shadings varied with the Sun position, solar radiation as well as the time. In general, on 20th June, the edge-shading effect reduced the energy output of PV system by 11%-15%, the pillar-shading effect reduced the energy output by 15%-19%, and both effects of edge-shading and pillar-shading reduced the energy output of PV system by 18%-35%. It is worth noting that the shading effect varies with the Sun position, it may cause much more energy loss in winter than in summer due to the increase of shading area.

In addition, the inverters’ energy output data were recorded. The inverter, which was connected to the PV modules made by Solgro, generated about 10.5 kWh on June 20, but the inverter connected to the PV modules made by Shell generated about 12.6 kWh, which is higher than that of Solgro’s PV modules by 20%. There are two reasons may explain why the energy output performance of Solgro’s PV modules was lower than that of Shell’s. On the one hand, the power performance of Solgro’s PV modules was decayed due to the aging problem. On the other hand, the edge-shading also reduced the power output of Solgro’s PV modules.

Ideally, the inverters connected to the PV modules made by Shell and Solgro should generate about 14 kWh on June 20 based on the solar radiation and PV modules’ temperature. Thus the energy loss caused by the shading effect was about 1.4 kWh for the Shell’s PV modules, which is accounted for 10% of the ideal energy output. These results agree well with the I-V testing results which are mentioned above. The energy loss for the Solgro’s PV modules is about 3.5 kWh, which is account for 25% of the ideal energy output. This energy loss is mainly caused by the both effects of edge-shading and pillar-shading, as well as the PV modules’ performance degradation.

In a word, it can be concluded that the main reasons causing the energy loss of the PV system are the shading problems. If the edge-shading and pillar-shading problems are solved, the annual energy output of the PV system could increase about 20%-24%.

REFERENCES

Abstract—Energy supply is a main requirement for economic and social development. The scarcity of energy resources and the negative environmental impact generated by the use of conventional fossil fuel has initiated the interest in the use of renewable resources. Electricity production is a major consumer of energy. Decisions have to be made as to which energy resource to use for electricity generation. Intensive global research investigating the various renewable energy technologies, and most importantly their economic feasibility is present and increasing steadily. Nations worldwide have set targets for the share of renewable resources in electricity generation. The rapid technological development and the increasing number of installations have helped in reducing the equipment cost, giving thus opportunity for developing economies to deploy available renewable resources. In Egypt, a plan has been devised to install a capacity of 2,800 MW of concentrating solar thermal power (CSP) and 700 MW of solar photovoltaic (PV) by 2027. The purpose of this research is to identify the most economical and sustainable technology mix to achieve the preset target. Levelized cost of electricity is the economic measure used for evaluating the economic feasibility of the proposed plan.

Keywords-levelized cost of electricity; mathematical modeling; planning; solar energy; sustainability;

I. INTRODUCTION

Electricity is an influential factor for economic and social development. Yet, in the process of electricity generation a considerable amount of natural resources is depleted, in addition to the resulting adverse environmental impact due to the extensive use of fossil fuel. This has been the main driver for switching to renewable energy resources. Solar energy has been used in different ways in providing thermal energy or in the production of electricity. Concentrating solar power (CSP) and photovoltaic (PV) systems are the technologies used for electricity generation. Concentrating solar power relies on the principle of concentrating solar normal irradiation through mirrors in order to heat steam. The generated steam is then used to drive turbines of conventional thermal power plants [1, 2]. Thus, the concentrating solar power provides a substitute of generating heat through burning of fossil fuel, eliminating the resulting CO₂ emissions. Currently parabolic trough is the most mature CSP technology, and most of the installations are of this type [2]. As for PV systems, the most mature technology is that of single and polycrystalline Silicone cells [3]. While CSP uses the direct normal irradiation which makes them suitable in hot dry regions with high direct normal irradiance, PV technology benefits from scattered and diffuse irradiance. The latter is thus suitable for regions with low solar irradiance.

The other major difference between the two generating technologies is the type of generated output. The generated energy from CSP can be directly used for heating the steam. On the contrary, PV systems generate direct current, which has to be converted to alternating current in order to enter the grid. The equipment required for the conversion process contributes to a new cost element known as the balance of the system (BOS) cost. Hence, to ensure the efficient and economic use of available solar resources, it is necessary to determine which type of technology to use to meet the required demand or preset target.

Egypt faces a steady increase in energy demand. According to the Egyptian Electricity Holding Corporation (EEHC), the annual production growth to as of fiscal year 2011/2012 was 7.2% [4]. Frequent electricity outage, especially during peak load times, reflects the shortage in supply of conventional fossil and natural gas which are currently the main source of energy generation. Hence, solar energy seems to be an attractive alternative for the country. Egypt is located within the Sun Belt countries with average annual direct normal solar irradiance ranging from 2,000 to 3,200 kWh/m²/year from North to South, with a daily sunshine duration ranging between 9 to 11 hours [5]. The prevailing meteorological conditions make the country suitable for solar energy applications. In 2007, Egypt has set a target to generate 20% of its total energy production from renewable resources by 2020 [4]. The New and Renewable Energy Authority (NERA) has set a five-year plans to meet the target specified by the Supreme Energy Council to generate 20% of the total electricity from renewable resources. The candidate resources are wind and solar energies. The established share of electricity generation through solar energy is 3,500 MW by 2027 [5]. In July 2012, the Egypt approved to set a target for 2,800 MW of concentrating solar thermal power (CSP) and 700 MW of solar PV by 2027 [6]. Since the interest in the deployment of renewable energy is overwhelming, advances in technology and applications of renewable resources are developing rapidly. This fact caused a noticeable decrease in the cost of solar panels. Hence, the predetermined targets and adapted strategies have to be reconsidered to ensure the sustainability of the devised plan.
The aim of this paper is to identify the optimum annual amount of solar energy installations in order to meet a predefined long term target. To this end, an integer nonlinear mathematical model is developed and solved to achieve the required deliverables. The remainder of this paper is structured as follows. Section II presents a brief review on the levelized cost of electricity (LCOE), the measure used for evaluating the economic feasibility of the energy generation technology. The proposed model is described in detail in Section III, and its implementation to the case of Egypt is presented in Section IV. Discussion and analysis of the obtained results are presented in Section V. Finally, the paper is concluded and areas of future research are highlighted in the Section VI.

II. LITERATURE REVIEW

The main barrier to intensively use renewable energy in electricity generation in emerging economies is an economic and financial one. Electricity generation using non-renewable fossil fuels is still more economic despite their negative environmental impact. Various economic performance measures are used to evaluate the economic viability of the different energy sources. Net present value, payback period, internal rate of return, and benefit to cost ratio are examples of renowned techniques. Yet, in the field of electricity generation, the levelized cost of electricity (LCOE) is the most commonly used economic measure [2, 3]. This measure compares the total costs to total revenue taking the time value of money into consideration. In other words, it determines the cost of electricity at the break-even point, i.e. at a point where revenue is equal to cost. The advantage of this measure is its generic nature allowing comparing the cost of electricity from different generation sources.

Several studies have been conducted to calculate the LCOE. The International Renewable Energy Agency (IRENA) presents a cost analysis of CSP and PV technologies. Calculations of the LCOE using investment, operation and financial one. Electricity generation using non-renewable fossil fuels is still more economic despite their negative environmental impact. Various economic performance measures are used to evaluate the economic viability of the different energy sources. Net present value, payback period, internal rate of return, and benefit to cost ratio are examples of renowned techniques. Yet, in the field of electricity generation, the levelized cost of electricity (LCOE) is the most commonly used economic measure [2, 3]. This measure compares the total costs to total revenue taking the time value of money into consideration. In other words, it determines the cost of electricity at the break-even point, i.e. at a point where revenue is equal to cost. The advantage of this measure is its generic nature allowing comparing the cost of electricity from different generation sources.

A review of the LCOE for PV technologies is presented in [7]. The model developed in [7] was used to assess the cost of electricity generation in Ontario, Canada. The cost of electricity generated from CSP is assessed in [8], where the authors’ main target was to develop a mathematical formulation of the LCOE from CSP during the period of 2010-2050. The model was applied to assess the global LCOE, and compare two roadmaps of renewable energy deployment. The proposed model is characterized by the consideration of the learning rate, which affects the installation costs.

An analytical model comparing the LCOE from PV and CSP was developed in [9]. The model is identical to the one presented in [8], yet it was used to compare the two solar energy technologies, and determine their grid parity.

The levelized cost of electricity for CSP plants in Egypt has been assessed in [10]. This study compared the cost of power generation from conventional sources to CSP and forecasted the cost of electricity in the future until 2050. Subsidy issues have also been addressed in [10] through the use of international fuel prices in calculating the LCOE from conventional resources.

Besides the direct costs incorporated in the electricity generation process, other costs relating to the generated emissions and environmental impact were also present. These costs are external costs, and have been addressed in a number of studies as in [11, 12].

The LCOE is used in this study as a measure to evaluate the economic feasibility of the proposed energy plan. Externalities costs are not included in the study, since both technologies, PV and CSP, are very similar in principle, thus no major difference is expected to prevail.

III. PROPOSED PLANNING MODEL

The proposed model aims at defining the amount of installed annual capacity of each solar energy technology type, CSP and PV, so as to minimize the total generation cost of electricity throughout the study period. The following assumptions are made:

- The installation time is considered constant and equal to two years.
- Installation cost decreases with the increase of the cumulative installed capacity.
- Costs are indicated in real 2010 dollar values.
- All installations are of the same technical specifications and their operation is optimized.
- All installations are located at optimum locations to maximize the benefit from available solar resources.

A. Decision Variables

\[ x(t) \]: Amount of capacity of CSP installed in year \( t \) (MW).

\[ y(t) \]: Amount of capacity of PV installed in year \( t \) (MW).

\[ C_a(t) \]: Cost of the CSP installed in year \( t \) ($).

\[ C_v(t) \]: Cost of the PV system installed in year \( t \) ($).

\[ X(t) \]: Cumulative installed capacity of CSP until year \( t \) (MW).

\[ Y(t) \]: Cumulative installed capacity of PV until year \( t \) (MW).

B. Parameters

\[ a \]: Annual target of cumulative CSP capacity to be installed until year \( t \) (MW).

\[ b \]: Annual target of cumulative PV capacity to be installed until year \( t \) (MW).

\[ C_s(0) \]: Cost of initial installed CSP system ($).

\[ C_v(0) \]: Cost of initial installed PV system ($).

\[ d \]: Degradation rate (%).

\[ E(t) \]: Annual amount of energy generated.
The objective function (1) is to minimize discounted total electricity generation cost for both types of solar energy technologies. The total generation cost is calculated by multiplying the LCOE of each technology in each year by its respective amount of energy generated. The amount of energy generated is the product of the cumulative installed capacity in year $t$, the number of hours per year (8760 hours), and the capacity factor. The LCOE in a certain year of each installation type is expressed in (7) and (8), respectively. Constraint (9) ensures that the cumulative total installed capacity of CSP and PV is equal to the predefined total target. Finally, (10) specifies the non-negativity and integrality constraints.

### IV. MODEL IMPLEMENTATION AND RESULTS

#### A. Implementation

The proposed model is used to assess the current solar energy plan of Egypt. The values of the different model’s parameters are summarized in Table I. Whenever the value is taken from previous studies, the reference number is indicated next to the value; otherwise it is an assumed value by the author. A conservative learning rate of PV technology of 10% is assumed. Restrictions on the model include setting the maximum annual installation of any technology type is limited to 400 MW, which is the quadruple of the current installed Kom Ombo station to reflect the practical limitation of resources and financing resources.

The model is solved via Excel Solver using the nonlinear method, and is applied to two scenarios. The first scenario is a replication of the current plan approved by the Egyptian authority, specifying the specific targets for CSP and PV to be

$$ LCOE = \left[ C(t) + \sum_{s=1}^{X_t} \frac{(OPEX+I) \times C(t)}{(1+r)^s} \right] \left[ \frac{(1-d)^s}{\sum_{s=1}^{X_t} (1+r)^s} \right] $$

$$ C_{I_{Y_{t}}} = C(0) \left( \frac{X(t)}{X(0)} \right) $$

$$ \sum_{t=0}^{T} x(t) = X(t) $$

$$ \sum_{t=0}^{T} y(t) = Y(t) $$

$$ \sum_{t=0}^{T} x(t) \leq a_i $$

$$ \sum_{t=0}^{T} y(t) \leq b_i $$

$$ X(t) + Y(t) = T $$

$$ x(t), y(t) \geq 0, \text{ integers} $$
2,800 MW and 700 MW, respectively. The second scenario investigates the effect of relaxing the technology specific targets, while fixing the total installation capacity target of 3,500 MW to be achieved in 2027.

### Table I. Model Parameters for CSP and PV

<table>
<thead>
<tr>
<th>Cost element</th>
<th>Symbol</th>
<th>Units</th>
<th>CSP</th>
<th>PV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial cost</td>
<td>$C(0)$</td>
<td>$/W</td>
<td>4.9</td>
<td>4</td>
</tr>
<tr>
<td>Initial cumulative installed capacity</td>
<td>$Q(0)$</td>
<td>$/W</td>
<td>20</td>
<td>[5]</td>
</tr>
<tr>
<td>Learning rate</td>
<td>$LR$</td>
<td>%</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Land cost</td>
<td>$L$</td>
<td>$($/kW)</td>
<td>24</td>
<td>[9]</td>
</tr>
<tr>
<td>Operation and maintenance expenses</td>
<td>$OPEX$</td>
<td>%</td>
<td>2</td>
<td>1.5</td>
</tr>
<tr>
<td>Annual insurance</td>
<td>$I$</td>
<td>%</td>
<td>0.5</td>
<td>0.25</td>
</tr>
<tr>
<td>Discount rate</td>
<td>$r$</td>
<td>%</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Solar resource</td>
<td>$S$</td>
<td>kWh/m²/year</td>
<td>2,800</td>
<td>[13]</td>
</tr>
<tr>
<td>Tracking Factor</td>
<td>$TF$</td>
<td>Dimensionless</td>
<td>0.9711</td>
<td>[9]</td>
</tr>
<tr>
<td>Performance factor</td>
<td>$\eta$</td>
<td>m³/kW</td>
<td>0.853</td>
<td>[9]</td>
</tr>
<tr>
<td>Annual degradation rate</td>
<td>$d$</td>
<td>%</td>
<td>0.2</td>
<td>0.6</td>
</tr>
<tr>
<td>Life time</td>
<td>$N$</td>
<td>years</td>
<td>30</td>
<td>25</td>
</tr>
</tbody>
</table>

*Note: A value of 1 instead of zero is assumed for initial capacity to avoid a zero in the denominator.*

B. Results

Figures 1 and 2 depict the cumulative annual installations of each technology type for scenario 1 and 2, respectively. The line in both figures indicates the cumulative total planned capacity. It may be observed that both scenarios succeed in meeting the total preset target. Yet, this target is achieved at different total discounted generation costs. For the first scenario, the resulting total generation cost over the planning horizon until 2027 is $2,733,225,069.02, while its value falls to $1,383,981,004.58 for the second scenario. The annual installations of each technology type for scenarios, 1 and 2, along with the annual LCOE of each technology are given in Tables II and III, respectively.

V. Discussion

Although the two studied scenarios achieve the final target of installing 3,500 MW by 2027, a substantial economic difference is present. Scenario 1, which enforces the ratio of CSP to PV to be 4:1 by 2027, has a total generation cost of almost double that required by scenario 2. This indicates that using the current market prices along with the effect of the learning rate in reducing the installation costs, PV is the most economical solar technology alternative for Egypt. Furthermore, the rapid technological improvement in PV and the increase in production volume will most probably cause further reductions in market prices.

Comparing the results of the two scenarios (Fig. 1 and 2), it is evident that the second scenario calls for the sole installation of PV systems. No further installations of CSP are recommended in scenario 2. On the contrary, a balance between PV and CSP is preserved to meet the target of 2,800 MW and 700 MW of CSP and PV, respectively in scenario 1. As mentioned above, these differences will double the total discounted generation cost over the planning horizon. This doubling in cost has to be justified, if scenario 1 is implemented. A possible reason for favoring one technology to the other despite its high cost, may be potential social and commercial benefits gained by installing a specific technology,
as for example the creation of the value chain of a specific product and the associated benefit thereof. CSP may be justified as an economic alternative for heat generation for specific industry. Yet, with respect to electricity generation, PV dominates it from an economic point of view.

It is noteworthy that the current implementation has set a maximum annual value of 400 MW for any of the considered generation technologies. This value seems to be relatively high; it presents the quadruple of the lately installed capacity in Kom Ombo, Egypt. Yet, a decrease of this value prohibits the achievement of the preset target of 3500 MW by 2027. This gives an indication of the current progress in implementing the renewable energy plan and an alert for reconsidering the preset target and its feasibility, as well as the necessity of studying possible obstacles in meeting the planned capacity.

Concerning the obtained annual LCOE from both technology types, it is comparable to the LCOE by conventional generation methods when calculated with international fuel prices neglecting thus the subsidies as indicated in [10].

VI. CONCLUSIONS

The current work has presented a mathematical model for planning utility scale solar energy in Egypt. The model relies on the use of the LCOE for assessing the economic feasibility of the proposed plan. The model resulted in determining the number of annual installations of PV and CSP to achieve the predetermined target by 2027. The results revealed that PV is more favorable under the present circumstances. Yet, the current tendency is towards installing CSP; currently 120 MW are installed, whereas PV is still progressing. Hence, the technical studies for PV installations have to take a higher priority to ensure sustainability of the energy plan.

The resulting LCOE from solar resources are comparable to the prices of electricity generated from conventional resources. Thus, the economic feasibility is no more a barrier to the deployment of renewable energy in developing economies. An important benefit obtained from the use of renewable energy is the reduction of fossil fuel consumption. This benefit is twofold for developing countries. First, it has a considerable environmental advantage of reducing CO₂ emissions. Second, it allows the reassignment of subsidy tied to fuel cost to other more vital sectors of the economy, health or education. This fact contributes to the sustainability of the energy plan.

The proposed model can be extended to plan different types of renewable energies. Planning conventional power generation technologies could also be accommodated by the model. Yet, in this case the inclusion of externalities may give more insight about the real cost of electricity. A multi-criteria decision approach may also be applied to address the different aspects of sustainability when setting plans for energy supply.

REFERENCES


Abstract—The Oscillating Water Column concept consists of two key elements, a turbine located in a pneumatic energy collection chamber and a doubly fed induction generator that converts energy extracted by the turbine into a form that can be returned to the network. Since the turbo-generator control requires the rotor angular velocity, removing the rotor speed sensor simplifies the hardware, with the consequent reduction in installation and maintenance costs which is even more relevant in the rough working sea conditions. In this particular case, a Luenberger based observer is considered and the effectiveness of the proposed control is shown by numerical simulations. Comparing these results with those obtained using a traditional speed sensor, it is shown that the proposed solution provides better performance since it allows a more reliable and robust performance of the plant.

Keywords—wave energy; control; observer

I. INTRODUCTION

The Spanish Council of Ministers on 11th November 2011 approved the Renewable Energies Plan for 2011-2020. This plan highlights the marine energy potential that Spain possesses with special emphasis in wave energy, with the potential to satisfy 15% of EU energy demand, cutting 136 MT/MWh off the CO2 emissions by 2050. In particular, Major efforts are being made in the Basque Country through the Nereida Project, promoted by EVE, which has developed an OWC integrated in a breakwater located in Mutriku and involves a €8M investment. The plant consists of 16 turbines, 18.5kW each, with an estimated overall power of 296kW (see Fig. 1) and has started operations in July 2011 [1-4].

In this ocean energy conversion system, the water surface inside a chamber moves up and down under the wave action causing to inhale and exhale air through the opening at the top. The bidirectional air flow is applied to a Wells turbine, which provides unidirectional rotation despite of the air flow direction [5,6]. Thus, the Wells turbine transforms the wave potential into mechanical energy that will be transmitted to a double feed induction generator, which feeds AC power to the grid. For that, two pulse-width-modulated three phase converters are connected back to back between the rotor terminal and the utility grid with a DC link. The stator circuit is directly connected to the grid while the rotor winding is connected via slip-rings to the rotor side converter [7].

The OWC system located in Mutriku implements a complementary modified antiwind up PID based valve control for incoming air flow into the turbine [8-11], while the Rotor and Grid Side Converters, RSC/GSC, are controlled independently. Considering that the ocean is a hostile environment, accuracy, robustness and sensitivity against parameter deviation can be improved by choosing closed loop observers [18,19]. In this sense, dynamic performance reliability has been achieved in this particular case considering a closed loop speed observer based in a Luenberger system to estimate the rotor speed from the measured stator voltages and currents [20,21].

After all these considerations and taking into account the cost effectiveness and improved performance that a speed observer can afford, this paper presents a new sensorless vector control scheme in order to improve the power extraction in the Mutriku OWC, whose results can easily be extended to other wave power extraction plants. The rest of the paper is organized as follows: In Section II the OWC is presented, and both its modules, the capture chamber and the turbine that generates energy, are explained. Next, in Section III, the proposed sensorless control scheme is stated. In the following Section IV, simulation results for a representative case-study comparing
II. MUTIKU OWC DESCRIPTION

A. Mutriku Wave Model and OWC Capture

In order to study regular waves, it is necessary to take into account the spectrum of the wave climate data, which measures the correlation between wave frequency and wave energy (see [22]). Taking these data into consideration, a regular wave may be modelled as follows

\[
P_{\text{of}} = \frac{\rho_{w} g A^2 \lambda}{16 T_{w}} \left[ 1 + \frac{4 \pi \phi / \lambda}{\sinh(4 \pi \phi / \lambda)} \right]
\]

(1)

\[
\lambda = \frac{g T_{w}^2}{2 \pi} \tanh(2 \pi \phi / \lambda)
\]

(2)

where \(P_{\text{of}}\) denotes the incident wave power, \(\rho_{w}\) is the seawater density, \(g\) the gravitational constant, \(A, h\) are the wave height and depth and \(\lambda, T_{w}\) the wave length and period.

A thorough overview of wave theory and models may be found in [23].

Thus, using data from the Bilbao-Vizcaya exterior buoy of the State Network Ports, the annual average wave height is around 2m, with period of about 10s and predominance of northeast swell type wave [24,25]. The breakwater housing the OWC plant is located at a depth of 5 m below MESTLW (Maximum Equinoctial Spring Tide Low Water) with respect to Level 0 at Mutriku port. The opening that transmits the wave oscillations to each air column is 3.2m high and 4m wide. The lowest point is at -3.40 m, so that the opening is always below sea level [26].

B. Turbo-Generator Module

In the Mutriku OWC, the turbines are fixed-pitch, which means that they present a robust performance due to the lack of airflow rectifying devices, since they always rotate in the same direction regardless of the airflow, and are vertically mounted with a butterfly type valve at the bottom to isolate the chamber if necessary. To minimize the height of the plant room the length of the turbo-generation assembly has been designed to be relatively small: 2.83 m high by 1.25 m maximum width and approximately 1200 kg (see Fig. 3).

The power available from the airflow in the OWC chamber, which parameters are presented in Fig. 2, may be expressed in terms of the air pressure duct, the air pressure and the kinetic energy as:

\[
P_{\text{aw}} = \frac{(dp + \rho_{v} v_{s}^2)}{2} v_{s} a
\]

(3)

where \(P_{\text{aw}}\) denotes the power available to the turbine, \(dp\) the pressure-drop across the rotor, \(\rho\) the air density, \(v_{s}\) the airflow speed and \(a\) the area of the turbine duct. For a complete description see [23].

The equations used for modelling the pressure drop across the rotor and the torque produced by turbine are (see [27]):

\[
dp = C_{p} K (1/a)(v_{s}^2 + (r \omega_{r})^2)
\]

(4)

\[
T_{r} = C_{T} r K [v_{s}^2 + (r \omega_{r})^2]
\]

(5)

where \(C_{p}, C_{T}\) are the power and torque coefficients, \(r\) is the mean radius of the turbine and \(\omega_{r}\) the angular velocity. The subscripts \(r, s\) shall in the following indicate either rotor or stator, respectively. \(K\) is the turbine constant defined as

\[
K = \rho b n l / 2
\]

(6)

with \(n\) the number of blades and \(l\) the blade chord length, so that it may be deduced that the torque

\[
T_{r} = dp C_{p} r a / C_{s}
\]

(7)

The flow coefficient, \(\phi\), is usually defined as the non-dimensional quantity corresponding to the tangent of the angle of attack at the blade tip. The flow coefficient is

\[
\phi = v_{s} / r \omega_{r}
\]

(8)

Finally, the flow rate and turbine performance can be calculated as

\[
q = v_{s} a
\]

(9)
\( \eta_r = T_{\omega_r} \frac{f_{d}}{f_{q}} \) (10)

On the one hand, the turbine set has fresh water injectors, which regularly clean the blades of any accumulations of encrusted salt, and on the other hand the turbo-generator control requires a precise knowledge of system parameters and of the rotor speed in particular. Thus, to remove the speed sensor rotor is to simplify the hardware, with the consequent reduction in installation and maintenance costs. A detailed description of the OWC numerical model may be found in [28].

III. A SENSORLESS CONTROL SCHEME

AC drives without speed sensors on the rotor shaft compose a common strategy for cost reduction and robustness, especially in hostile environments ([29-35]). In this section, a sensorless control scheme with an observer for the induction rotor speed based on a disturbance model is presented. The proposed observer aims to accurately estimate the rotor angular velocity by employing the stator current and stator voltage as input variables in a closed loop observer structure that was first introduced in [18].

### TABLE I

<table>
<thead>
<tr>
<th>dp<a href="Pa">AVERAGE</a></th>
<th>slip[AVG] (%)</th>
<th>Flow Coef φ</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–5500</td>
<td>-0.56</td>
<td>0 – 0.2987</td>
</tr>
<tr>
<td>5500–5790</td>
<td>-2.34</td>
<td>0 – 0.2999</td>
</tr>
<tr>
<td>5790–5975</td>
<td>-4.13</td>
<td>0 – 0.2995</td>
</tr>
<tr>
<td>5975–6175</td>
<td>-6.00</td>
<td>0 – 0.2995</td>
</tr>
<tr>
<td>6175–6375</td>
<td>-7.90</td>
<td>0 – 0.2995</td>
</tr>
<tr>
<td>6375–6600</td>
<td>-9.86</td>
<td>0 – 0.2995</td>
</tr>
<tr>
<td>6600–6850</td>
<td>-11.94</td>
<td>0 – 0.2999</td>
</tr>
<tr>
<td>6850–7100</td>
<td>-14.06</td>
<td>0 – 0.2998</td>
</tr>
<tr>
<td>7100–7375</td>
<td>-16.28</td>
<td>0 – 0.2998</td>
</tr>
<tr>
<td>7375–7670</td>
<td>-18.60</td>
<td>0 – 0.2999</td>
</tr>
</tbody>
</table>

A point tracking technique will be implemented for the control to track a curve that yields the maximum possible power for any given environmental conditions. This Tracking Characteristic Curve (TCC) is predefined for each turbine, by adjusting the shaft speed of the OWC turbo-generator, so that the flow coefficient \( \phi \) remains bounded, yielding a maximum stalling-free torque coefficient \( C_t \). Thus, for a given pressure drop input \( dp \) there is a unique generator slip and a power reference required to satisfy the conditions of maximum wave energy extraction. In our particular case, this TCC is achieved based on a previous study of the Wells turbine at hand using the characteristic curve provided by the manufacturer (see Fig. 3), the required slip values are shown in Table I.

The control and its design requires taking into account the dynamics of the turbo-generator module. In particular, in the DFIG-based OWC generation system, the maximum power objective is achieved by regulating the current of the rotor in the RSC. In order to achieve independent control of the stator active power, \( P \), and reactive power, \( Q \), the direct and quadrature components of the rotor currents \( i_{dq} \), \( i_{dr} \), are used to provide the required voltage signal \( v_{dq} \), \( v_{dr} \) by PI controllers. For a detailed description of the different parts of the control scheme see [36], further information about DFIG control devices by means of RSC and GSC may be found in [37-39].

A simple implementation of a Luenberger based observer for the rotor flux and angular velocity will be proposed. Field oriented decoupling is applied, giving all expressions in a reference frame and other vector components. Both disturbance and flux vectors are the estimated components of the stator voltage, current and flux vector of the rotor in the reference frame and

\[
\frac{d\hat{\psi}_d}{dt} = a_1 \hat{i}_d + a_2 \hat{\psi}_q - a_3 \omega_r \hat{\psi}_d + a_4 v_d + k_1 (\hat{\psi}_d - \hat{i}_d) , \quad \frac{d\hat{\psi}_q}{dt} = \frac{a_5 \hat{i}_q + a_6 \hat{\psi}_d - a_7 \omega_r \hat{\psi}_q + a_8 v_d + k_1 (\hat{\psi}_q - \hat{i}_q)}{L_{ds}} \quad \text{(11)}
\]

\[
\frac{d\tilde{\omega}_r}{dt} = a_3 \hat{i}_d + a_4 \hat{\psi}_d + \tilde{\omega}_r + k_2 (\hat{\psi}_d - \hat{\psi}_q) \quad \text{(12)}
\]

where \( \psi_d, \psi_q, \hat{i}_d, \hat{i}_q, \hat{\psi}_d, \hat{\psi}_q \) are the estimated component of the rotors flux and angular velocity will be proposed. Field oriented decoupling is applied, giving all expressions in the reference frame and

\[
\begin{align*}
\frac{d\hat{\psi}_d}{dt} &= a_1 \hat{i}_d + a_2 \hat{\psi}_q - a_3 \omega_r \hat{\psi}_d + a_4 v_d + k_1 (\hat{\psi}_d - \hat{i}_d) \quad \text{(11)} \\
\frac{d\hat{\psi}_q}{dt} &= \frac{a_5 \hat{i}_q + a_6 \hat{\psi}_d - a_7 \omega_r \hat{\psi}_q + a_8 v_d + k_1 (\hat{\psi}_q - \hat{i}_q)}{L_{ds}} \\
\frac{d\tilde{\omega}_r}{dt} &= a_3 \hat{i}_d + a_4 \hat{\psi}_d + \tilde{\omega}_r + k_2 (\hat{\psi}_d - \hat{\psi}_q) \quad \text{(13)}
\end{align*}
\]

The structure of this observer is based on treating as disturbances \( \zeta_d, \zeta_q \) the corresponding vectors \(\omega_r \hat{\psi}_d, \omega_r \hat{\psi}_q\), so as to remove the coupling between co-coordinates.

\[
\begin{align*}
\frac{d\zeta_d}{dt} &= k_1 (\hat{i}_d - \tilde{i}_d) \quad \text{(14)} \\
\frac{d\zeta_q}{dt} &= -k_1 (\hat{i}_q - \tilde{i}_q) \quad \text{(15)}
\end{align*}
\]

The disturbance vector has the same angular velocity as all other vector components.
have the same phase and proportional amplitudes so that the velocity may be estimated as
\[ \hat{\omega}_r = S \left( \frac{\psi_{rd}^2 + \psi_{rq}^2}{\psi_{rd} + \psi_{rq}} \right) + k_4 (V - V_f) \]  
(17)

where \( S \) denotes the sign of the angular velocity. The observer gains \( k_1, k_2 \) have small values and are selected experimentally while \( k_4 \) depends on the rotor speed

\[ k_2 = a + b \left| \hat{\omega}_r \right| \]  
(18)

being \( a \) and \( b \) constants and \( \left| \hat{\omega}_r \right| \) the absolute value of the estimated filtered rotor speed. \( V_f \) denotes the filtered signal of the control \( V \), which is defined as

\[ V = \psi_{rd} \omega_d - \psi_{rd} \omega_q \]  
\[ \frac{dV_f}{d\tau} = \frac{1}{T_s} (V - V_f) \]  
(19)

A comprehensive description of Luenberger observers may be found in [40,41]. As it has been explained before the stator is connected to the grid, so that the influence of the stator resistance is small and the stator magnetizing current \( i_{ms} \) is considered to be constant [42]. For this purpose it is assumed that the machine works away from the magnetic saturation limits. Thus, \( T_s \) may be defined as:

\[ T_s = -K_T i_{qr} \]  
(20)

Therefore, the generator slip may be controlled by regulating the rotor current \( i_{qr} \), while the stator reactive power \( Q_s \)

\[ Q_s = \frac{3}{2} \alpha_s L_s \omega (i_{ms} - i_{qr}) \]  
(21)

may be controlled by regulating the rotor current \( i_{qr} \). Consequently, from \( T_s = -K_T i_{qr} \) with \( K_T \) being a torque constant and taking into account that \( P = T \omega \), the sensorless controller that has been designed solves the power tracking problem for DFIG-based OWC power plants in a hostile environment since it allows to achieve maximum power extraction by matching the desired generator slip reference to avoid the stalling behaviour.

IV. SIMULATION RESULTS

As it has been indicated, the NEREIDA OWC demo project [3] includes 16 Wells turbines in a newly constructed rubble mound breakwater in the Basque location of Mutriku, in the northern coast of Spain. The main objective of this section is to demonstrate the viability of the proposed rotor angular velocity observer to help develop this OWC technology with Wells turbine power take-off for future commercial plants. For this reason, the simulation data and wave model have been chosen taking into account the spectrum of the wave climate of Mutriku and the OWC system parameters are listed in Table II.

Given the proposed speed estimator, the maximum power tracking performance of the system has been tested by means of numerical simulations The control strategy is composed of a double feed induction generator, DFIG, which is controlled with a vector field oriented strategy, a crowbar and an air flow control. The crowbar protects the RSC, enforcing short-circuit when overcurrents in the rotor occur while the air valve regulates the incoming air flow so as to avoid stalling. Finally, the main control loop regulates both active and reactive power of the DFIG using the currents as control variables to match the modified power reference. See reference [36] for a detailed explanation of this control and references [43] for a summary on fault tolerance control.

This sensorless control has been applied considering a scenario where waves produce a typical variation for 7000Pa maximum pressure drop input and a balanced grid fault has been implemented with an 85% reduction of the grid voltage applied at 10s and cleared at 15s. For comparison purposes, the same study case has been considered with and without sensor. In particular, in Fig. 4 the rotor flux obtained with the proposed sensorless controller is plotted so as to compare it with that obtained using a control where the velocity is computed via a traditional sensor, plotted in Fig. 6. As it may be observed, there exists no significant difference between them.

![Fig. 4. Rotor flux for 7000Pa maximum pressure drop input (observer)](image)

![Fig. 5. Rotor flux for 7000Pa maximum pressure drop input (sensor)](image)

Similarly, it may be seen in Fig. 6 that after a transitory, due to the fault-ride-through capability of the control scheme, \( \omega_b \) does not increase during the voltage dip, which also affects the flux value. Besides, it should be highlighted that in the Mutriku WOC technical solution, the given reference is the pressure...
drop whilst the reference for the rotor angular velocity, $\omega_r^*$, is not readily accessible, so that the proposed estimator with stator current based feedback suits perfectly the requirements of the system.

![Fig. 6. Rotor angular vel. for 7000Pa max pressure drop input (observer)](image)

Under these conditions it may be seen in Fig. 7 and Fig. 8 the effect of the fault over the active and reactive power at the stator terminals both with sensor and with the proposed observer. In both cases, there is no active power consumption during the fault period and the reactive power overshoot during both the start and clearance of the fault is acceptable. Besides, the generator oscillatory dynamics have been controlled, while giving reactive power to the grid so that it contributes to the attenuation of the voltage dip. In this context, both figures show that the plant generates active and reactive power during the fault period and, particularly, during the fault recovery, since it is only during 100 ms after the fault recovery that the generator absorbs a little amount of power (less than 60% of the nominal power). These voltage dips are usually caused by remote grid faults in the power system and would normally require disconnecting the generator from the grid until the faults are cleared. However, normative relative to this requirement tends to enforce maintaining active power delivery and reactive power support to the grid, so that grid codes now require ride through voltage dips like the one presented in this article.

![Fig. 7. Active and reactive power generated using sensorless control](image)

![Fig. 8. Active and reactive power generated using traditional control](image)

V. CONCLUSION

This paper has proposed a novel implementation of a Luenberger observer to estimate the rotor angular speed for the control of the Matriku OWC wave power generation demo plant within the NEREIDA project from the Basque Energy Board (EVE). This closed loop observer is based in a Luenberger system and estimates both rotor angular velocity and fluxes using the measured stator voltages and currents. Due to the nature of this observer, the rotor angular velocity is computed from its flux and a vector of cross-product state variables that are treated as disturbances. In order to verify the performance of the proposed observer to obtain maximum power extraction capability in the plant even when it is subject to voltage dips, a comparative study for the power generated with a traditional sensor and with the proposed observer has been performed. A point tracking technique has been implemented so that the control system tracks a curve that yields the maximum possible power from the sea and no substantial differences between them have been found. As a result, it can be concluded that the proposed observer scheme improves the plant reliability by increasing reliability and disturbance rejection while reducing cost and, therefore, improving the power extraction when applied for maximum power generation purposes.

REFERENCES


Session 2: Environmental Challenges, Fuel Options, Distributed Generation and Renewable Energy Managements

Protection of the distribution lines with distributed generation against lightning overvoltages in the context of smart grids
(Authors: M. A. Araújo, R. A. Flauzino, O. E. Batista, L. A. Moraes, C. H. R. Martins)

(Authors: José Javier García, Regina Enrich, Marc Torrent-Moreno)

Potential of Biofiltration for VOCs and Odor Emissions Control in African and Caribbean Countries
(Authors: J. Perez, M. Reiser, K. Fischer)
Protection of the distribution lines with distributed generation against lightning overvoltages in the context of smart grids

Department of Electrical and Computing Engineering
University of São Paulo – USP
São Carlos, Brazil
marcel.araujo@usp.br, rafflauzino@sc.usp.br, oureste.batista@usp.br, lucas.moraes@usp.br, martins.cesar@usp.br

Abstract—The new technologies of energy supply and analysis of the operation of electrical systems, brought by the distributed generation and by the smart grid concepts, emphasize even more the importance of conservation of security and reliability of distribution networks. This occurs due to the sensibility of modern equipment being introduced in these networks. At this context, the protection of electric power systems against lightning overvoltage has increased its relevance in the search for greater continuity, reliability and quality of the energy supplied. Thus, in this paper it is simulated the performance of a protection system, constituted by the metal-oxide surge arresters, against lightning overvoltage, in the presence of distributed generators and of concepts of smart grids. It is also performed a technical/economic feasibility study through the development of a procedure for the definition of the best sizing, allocation and quantification of the surge arrester to the protection of a distribution line.

Index Terms—Distributed generation, smart grids, lightning overvoltage, overvoltage protection, metal-oxide surge arrester.

I. INTRODUCTION

The current conjuncture of social, economic and environmental issues related to the production and consumption of electricity, is promoting the adoption of new technologies for the production, transmission and distribution of energy. The growth of pollution, the shortage of energy resources, the climate changes and the increase of environmental awareness by the population are intensifying the search for sustainable solutions and for the environmental preservation by agents producers, traders and consumers of energy [1] - [3].

In this context, within the constant search for technologies to improve the processes of generation and distribution of energy, the application of the methodologies and procedures of Distributed Generation (DG) and Smart Grids (SG) are being consolidated and are spending more and more efforts for its implementation [4], [5]. The use of DG and SG improves the reliability and continuity of the operation of Electric Power Systems (EPSs), since they propose the use of measuring devices, control, sensing, communication and automation [6], [7]. Thus, the EPSs become able to detect failures with greater accuracy and fix them or interrupt the supply of energy in a shorter time, preventing damage to the largest possible number of consumers. However, at the same time, these devices increase the sensitivity of EPSs to the variations of voltage and current. This occurs due to the use of equipment composed by electronic circuits, which are more sensitive to overvoltage and overcurrent caused by switching and direct and indirect lightning in the network, requiring greater attention to the protection systems [8], [9]. In addition to this aspect, the increase of the intensity and occurrence of storms due to climate changes makes the studies of protection of the EPSs even more relevant, more specifically about protection against the incidence of lightning.

Among the protection systems against overvoltages, the Lightning Protection Systems (LPSs) and the grounding systems stand out. The LPSs consists of Surge Arresters (SAs), which lead the atmospheric discharge to the ground, at the same time they limit voltage on the equipment to which they provide protection. This limit voltage is composed by the sum of the voltage discharge of the SA and by the induced voltage developed by the discharge current between the SA line and ground leads [10]. Some of the most important problems, which can be analyzed by a study of LPSs are:

- Analysis of lightning induced voltages [11];
- Reduction of unplanned shutdowns which result voltage sags and load shedding [12];
- Definition of the location and number of SAs to be installed [13];
- Determination of influence of SA placement on phases considering the possibility of shutdowns of the line based on the level of energy absorption of SAs [13], [14];
• Analysis of the use of shield wire and SAs with or without spark-gap and assessment of the performance of a line in the event of lightning, so as to include critical regions [15].

The SAs also excel in situations where there is utilization of DG and SG because they are devices against surge that can operate in conditions in which the power flow can be unidirectional as well as bidirectional.

At this conjuncture, one of the purposes of the application of the concepts of smart grids is to provide the infrastructure necessary for an optimized integration between EPSs and the connection and disconnection of DG. Studies about this integration point as benefits for the network aspects related to improving the voltage profile, reduction in transmission and distribution losses, increase reliability, and support peaks consumption. However, some challenges are also highlighted to this integration, such as high initial cost, loss of radiality, coordination problems and selectivity, increased levels of short-circuit, voltage fluctuations and introducing inter-harmonics [16], [17].

Thus, this paper presents a protecting procedure against surges of atmospheric origin based on the application of SAs. For this, the consequences of the incidence of direct lightning in a distribution line were investigated in a context with situations of connection and disconnection of distributed generators.

In the sequence, Section II demonstrates how the distributed generators were modeled. Section III presents the main aspects related to overvoltages of atmospheric origin. The Section IV gives details about the selection, modeling and implementation of metal-oxide SAs. Finally, Section V and VI will show respectively the results obtained and the conclusions of the paper.

II. MODELING OF DISTRIBUTED GENERATORS

According to Fig. 1 the distributed generators provide bidirectional flow of energy and they are characterized by being located close to consumer centers, constituting themselves by renewable sources such as photovoltaic panels, wind turbines, and small plants of cogeneneration and microgeneration. Also, DGs bring as main advantages their low environmental impact, reduced time to implantation, smaller charging of networks, diversification of energy matrix, decentralized dispatch and utilization of small generating units, among others [3], [7] [9], [18].

For the simulations in this article, it was adopted the input and output of DG by means of synchronous generators connected to the network by transformers of 500 kVA.

The generators were represented by their subtransient model, with armature resistance of 0.03 pu, subtransient synchronous reactance of 0.24 pu, active power of 425 kW, and configured in control mode terminal voltage (1 pu), that is, the bus at its terminals is of the type PV.

Figure 1: Distribution System with Distributed Generation [18].

III. OVERVOLTAGES OF ATMOSPHERIC ORIGIN IN ELECTRIC POWER SYSTEMS

The incidence of lightning on the conductors of TLs and DLs (direct lightning) or in the vicinity (indirect lightning) can cause overvoltages of high magnitude in the lines. The induced voltages by these discharges are the main element responsible for unplanned outages of transmission lines and distribution. If the amplitudes of these overvoltages exceed the levels that the system can withstand, levels that in applications with electronic devices of DG and SG are considered relatively low, disruptive discharges will occur, which can evolve into electric arcs. This can result in faults between one or more phases and ground and the need to actuate protection devices against overvoltages and overcurrents.

In TLs and DLs with nominal voltages below 200 kV, without protective devices, such as the lime analyzed in this paper, direct lightning strikes cause overvoltages and dielectric failure, resulting in the burning of equipment and probably physical damage to its components. The addition of these overvoltages with the high penetration of DG promotes an impact on the capability to short circuit, transient stability of the system, coordination, protection, voltage control and power quality. These circumstances can significantly influence the good functioning and performance of the protection of the power system [19], [20].

Although the direct incidence of lightning on DLs is less frequent than the indirect one, the study of methods of protection against overvoltages of atmospheric origin on these lines is of great value, especially in the context of SG and DG. This fact is justified due to the higher sensitivity introduced by the use of SG and DG, greater severity of overvoltages caused by this type of discharge, and because on lines of less occupied urban areas and on open field lines in rural areas, the probability of occurrence of direct lightning is more likely.

IV. MODELING OF METAL-OXIDE SURGE ARRESTER

The entry of DG units in EPSs has promoted changes in the behavior of distribution networks, modifying its passive characteristic, with unidirectional flow from the substation to the consumers, to active, with bidirectional flow. This
bidirectionality can be ascertained by the presence of agents that consume, generate and store energy, resulting in the loss of the characteristic radial EPSs and changing the power flow in your direction and magnitude. Another important impact of the insertion of DG is the change in direction and magnitude of fault currents, which together with the alternation of power flow, cause problems of coordination and selectivity for the protection systems, which are designed from the radial characteristic EPSs [8], [21], [22].

In this context, among the protective devices, the metal-oxide SAs, or zinc oxide (ZnO) SAs stand out due to their capacity to act robustly in systems with unidirectional or bidirectional power flow. Thus, it will be modeled and implemented to protect the DL under study, font of the presence of the employment of DG and SG.

The metal-oxide SAs, currently, are the type often used on DLs and TLs by virtue of the nonlinear characteristic of their blocks of resistors in the region of low intensity current, because this property implies a lower drained leakage current. Other features that make them the most used are the short response time to transients, low residual voltage, high thermal stability and high energy absorption capacity when faced with temporary and transient overvoltages [23], [24].

Thus, the requirements for implementation of the Pinceti and Giannettoni model [25] in ATP software, run in the graphical interface ATPDraw will be presented next, as well as the electrical characteristics of the SAs needed on the line employed in this analysis.

A. Characteristics of Pinceti and Giannettoni Model

The Pinceti and Giannettoni model was chosen because it represents adequately the dynamic characteristics of the SA, it requires only the electrical parameters to build the circuit and it does not need iterative corrections during its computer simulations. These features make it a very attractive model in terms of computational effort and the ready availability of necessary data from manufacturers.

Fig. 2 illustrates the model proposed by Pinceti and Giannettoni, and (1) and (2) demonstrate the parameters needed to determine inductances $L_0$ and $L_1$. In addition, in (1) and (2), $V_n$ is the nominal voltage of the varistor, $V_{R8/T2}$ is the residual voltage due to a current surge of modulus 10 kA and 1.2 $\mu$s rise time, $V_{R8/T2}$ is the residual voltage for a current of wavefront 8 $\mu$s and $V_{R8/20}$ is the residual voltage for a current of 10 kA and waveform 8x20 $\mu$s.

The characteristics of nonlinear resistors $A_0$ and $A_1$ are determined by multiplying voltages $A_0$ and $A_1$ in Table I by the residual voltage due to a surge current of modulus 10 kA and 1.2 $\mu$s rise time, and will be defined in subsection B.

\[
L_0 = \frac{1}{12} \frac{V_{R1/T2} - V_{R8} T_2}{V_{R8} T_2 V_n} \mu H 
\]

(1)

\[
L_1 = \frac{1}{4} \frac{V_{R8/T2} - V_{R8}}{V_{R8} T_2 V_n} V_n \mu H 
\]

(2)

B. Electrical characteristics of the modeled line and surge arrester

As from the data of the line operation, of the overvoltage investigated by the simulations of lightning, connections and disconnections of DG, and through the information contained in a catalog of SAs, the SAs were sized for the line under study.

Some parameters of the line and of the region where it is located were needed, such as the nominal voltage, equal to 69 kV, the phase voltage, equal to 39.8 kV, and the keruonic index ($I_k$) of the region of the line approximately equal to 60, according to the Brazilian standard [26], which results in a Flash Density (FD) of 1.89, calculated by (3).

\[
FD = 0.0024 I_k^{1.63}. 
\]

(3)

From these data and the manufacturer’s information contained in [27], the electrical characteristics of the SAs modeled in this article were defined. For each system voltage, the combined data from Tables II, III and IV, which contain the guaranteed protection characteristic of SAs, provide a range of values for the maximum system voltage ($U_m$) and for the nominal voltage ($U_r$).

<table>
<thead>
<tr>
<th>Maximum System Voltage</th>
<th>Nominal Voltage</th>
<th>Maximum Residual Voltage for 8x20µs Wave of Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>$U_m$</td>
<td>$U_r$</td>
<td>5kA</td>
</tr>
<tr>
<td>[kVrms]</td>
<td>[kVrms]</td>
<td>[kV peak]</td>
</tr>
<tr>
<td>52</td>
<td>42</td>
<td>103</td>
</tr>
<tr>
<td></td>
<td>48</td>
<td>118</td>
</tr>
</tbody>
</table>
TABLE III: MINIMUM UR OF SURGE ARRESTER FOR LIGHTNING, ADAPTED FROM [27].

<table>
<thead>
<tr>
<th>System Grounding</th>
<th>Fault Duration</th>
<th>System Voltage Um [kV]</th>
<th>Minimum Nominal Voltage Ur [kV]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective</td>
<td>≤1s</td>
<td>≥100</td>
<td>≥0.8xUm</td>
</tr>
<tr>
<td>Effective</td>
<td>≤1s</td>
<td>≥123</td>
<td>≥0.72xUm</td>
</tr>
</tbody>
</table>

TABLE IV: LIGHTNING PROTECTION CHARACTERISTIC OF SURGE ARRESTER, ADAPTED FROM [27].

<table>
<thead>
<tr>
<th>Maximum System Voltage</th>
<th>Nominal Voltage Ur</th>
<th>External Insulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Um [kVrms]</td>
<td>1.2/50 μs</td>
<td>60 Hz</td>
</tr>
<tr>
<td></td>
<td>dry</td>
<td>humid (10s)</td>
</tr>
<tr>
<td>[kVpeak]</td>
<td>[kVrms]</td>
<td>[kVpeak]</td>
</tr>
<tr>
<td>52</td>
<td>42-60</td>
<td>310</td>
</tr>
<tr>
<td></td>
<td>66</td>
<td>370</td>
</tr>
</tbody>
</table>

Considering that the chosen SA must have a continuous operating voltage above the system nominal voltage, using the Table II, it was adopted one of 52 kV, a value immediately above the phase voltage of the line. To determine Ur, Table III was analyzed, according to which Ur ≥ 0.8xUm, since the grounding of the line is taken as effective and thus Um ≤ 100 kV; that is, Ur is 41.6 kV. Thus, in Table II the value equal to or just above that found for Ur should be taken; thus, the Ur adopted is 42 kV.

Next, the parameters of (1) and (2) were determined from the data in Tables II and IV, which gives $V_e$ equal to 42 kV, $V_{R1/T2}$ equal to 310 kV, $V_{R8/T2}$ and $V_{R8/20}$ equal to 109 kV, $L_1$ equal to 19.36 µH, $L_2$ equal to 6.45 µH and characteristics of nonlinear resistors $A_o$ and $A_i$, as shown in Table V.

TABLE V: CHARACTERISTICS OF NONLINEAR RESISTOR IN THE SURGE ARRESTER MOOLED.

<table>
<thead>
<tr>
<th>Current (kA)</th>
<th>2e</th>
<th>0.1</th>
<th>1</th>
<th>3</th>
<th>10</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_o$, Voltage (pu)</td>
<td>251.1</td>
<td>301.9</td>
<td>326.1</td>
<td>343.5</td>
<td>370.4</td>
<td>395.9</td>
</tr>
<tr>
<td>$A_i$, Voltage (pu)</td>
<td>193.1</td>
<td>244.3</td>
<td>268.5</td>
<td>385.8</td>
<td>312.8</td>
<td>338.2</td>
</tr>
</tbody>
</table>

C. Implementation and simulation of the surge arrester model

The circuit in Fig. 2 was implemented with nonlinear resistors parameterized with data previously recorded with a 1 MΩ linear resistor, to avoid numerical instabilities during the simulation. A source was used to simulate lightning of waveform 1.2x50 μs and discharge current 10 kA. The response of the simulation, is displayed in Fig. 3, in which the consistency of the behavior of the model may be noted, because when the SA was subjected to a voltage greater than its nominal voltage, its impedance fell, allowing the atmospheric impulse current to be dissipated. Also, it is verified that the value of the overvoltage resulting was limited, and recovered the high impedance value of SA after the end of the request voltage.

V. RESULTS

To analyze the incidence of direct lightning on the line under study, initially, simulations were carried out with lightning with waveform 1.2x50 μs, discharge currents 10 kA, 4.5 kA or 2.5 kA, and impedance of the air ionization channel 1 kΩ or 3 kΩ.

Simulated discharges were applied at points 2, 5 and 8 of the line, with the connection and disconnection of four generators at points 1, 4, 6 and 9, as illustrated in Fig. 4. Through these simulations it was found that at the most critical condition, that is, at the condition with the highest overvoltage, the maximum overvoltages generated are of 2,542 kV for positive voltage and -2,102 kV for negative voltage, without the connection any of the generators, and 2,438 kV and -2,114 for the system with four generators connected at the same time, in the points 1, 4, 6 and 9. In both situations such overvoltages occurred in the case whereby the discharge current was 10 kA, the resistance of the ionization channel 3 kΩ and lightning was applied and measured at point 5 on the line.

From the most critical situation, new simulations of lightning were carried out, with the addition of 2, 3 and 5 sets of SAs at points 1 and 9, 1, 5 and 9, and 1, 3, 5, 7 and 9, respectively. It should be noted that a set of SAs consists of 3 SAs, one per phase, and that the overvoltages on the line were acquired by meters located at points 2, 5 and 8, in all situations.

With the addition of 2 sets of SAs at the ends of the line, that is, at points 1 and 9, the overvoltages generated on the line and voltages and currents in the SAs for the system with
and without DG were obtained, as exposed in Tables VI and VII respectively. From these tables it is concluded that 2 sets of SAs are not sufficient to protect the line, since the maximum overvoltage measured at point 5 is 2,586 kV and 2,621 kV respectively. However, it is observed the correct functioning of the SA, because the maximum residual voltage measured on its terminals was 265 kV and 292 kV, which does not exceed the limit of 310 kV established by the manufacturer. In addition, the greatest currents found, which were 8.7 kA and 8.9 kA, also do not exceed the limit of 10 kA withstand able by the SA.

Table VI: Maximum voltage and current value on the line with 2 sets of surge arresters and without the presence of DG.

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Point of Measurement</th>
<th>Phase</th>
<th>Phase A</th>
<th>Phase B</th>
<th>Phase C</th>
</tr>
</thead>
<tbody>
<tr>
<td>SA 1</td>
<td>Current [A]</td>
<td>1</td>
<td>3,181</td>
<td>-3,049</td>
<td>8,754</td>
</tr>
<tr>
<td></td>
<td>Voltage [kV]</td>
<td>1</td>
<td>-233</td>
<td>-220</td>
<td>265</td>
</tr>
<tr>
<td>SA 2</td>
<td>Current [A]</td>
<td>9</td>
<td>2,909</td>
<td>2,118</td>
<td>8,159</td>
</tr>
<tr>
<td></td>
<td>Voltage [kV]</td>
<td>9</td>
<td>-209</td>
<td>-184</td>
<td>242</td>
</tr>
</tbody>
</table>

Table VII: Maximum voltage and current value on the line with 2 sets of surge arresters and with the presence of DG.

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Point of Measurement</th>
<th>Phase</th>
<th>Phase A</th>
<th>Phase B</th>
<th>Phase C</th>
</tr>
</thead>
<tbody>
<tr>
<td>SA 1</td>
<td>Current [A]</td>
<td>1</td>
<td>4,358</td>
<td>-2,943</td>
<td>8,958</td>
</tr>
<tr>
<td></td>
<td>Voltage [kV]</td>
<td>1</td>
<td>-223</td>
<td>-171</td>
<td>292</td>
</tr>
<tr>
<td>SA 2</td>
<td>Current [A]</td>
<td>9</td>
<td>3,254</td>
<td>2,304</td>
<td>8,289</td>
</tr>
<tr>
<td></td>
<td>Voltage [kV]</td>
<td>9</td>
<td>-197</td>
<td>-167</td>
<td>253</td>
</tr>
<tr>
<td>Meter of voltage [kV]</td>
<td>2</td>
<td>-792</td>
<td>-496</td>
<td>1,687</td>
<td></td>
</tr>
<tr>
<td>Meter of voltage [kV]</td>
<td>5</td>
<td>-1,873</td>
<td>-1,381</td>
<td>2,621</td>
<td></td>
</tr>
<tr>
<td>Meter of voltage [kV]</td>
<td>8</td>
<td>938</td>
<td>582</td>
<td>2,009</td>
<td></td>
</tr>
</tbody>
</table>

Later, the results in Table VIII and IX were obtained with the addition of 3 sets of SAs at points 1, 5 and 9, as illustrated in Fig. 5. Analyzing these tables it can be observed that with this configuration the line is protected, since the maximum overvoltage measured in this situation was found at point 2 and is 2,44 kV and 278 kV for the system with and without DG, respectively. Moreover, again the residual voltage and the current in the SAs did not exceed the limits established by the manufacturer, because they were 162 kV and 196 kV, and 9.4 kA and 9.5 kA, to input and output DG.

Finally, adding 5 sets of SAs in points 1, 3, 5, 7 and 9, new data were obtained, where it is found that the line is also protected with this configuration, because, again, the maximum overvoltage was measured at point 2 and is 237 kV and 271 kV for the system with and without DG, respectively. Furthermore, once again, the residual voltage and the current in the SAs did not exceed the limits established by the manufacturer, because they were 179 kV and 203 kV, and 9.2 kA for both cases.

VI. CONCLUSIONS

Analyzing the maximum overvoltage resulting from lightning measured on the line, configured with 5 and 3 sets of SAs, it is found that they exhibit small differences between their values. For the line without inserting of the DG the difference between these overvoltages is approximately 2.9% and for the system with DG is 6.5%. Therefore, considering the technical/economic feasibility of the project to protect the line, the best solution in both cases is the use of only 3 sets of SAs arranged in points 1, 5 and 9, due to the protection offered and the high cost of purchase and installation of these devices.

Examining the voltage measured by the meters allocated in points 2, 5 and 8 of the line, it can be concluded that the introduction of DG promotes benefits to the system, such as improved profile of the voltage, since there is less variation between the maximum and minimum points of the measured voltages. Another positive point of the inclusion of DG is loss reduction during distribution, evidenced by the values slightly higher of voltages measured with the protected line by 3 and 5 sets of SAs when compared to values without DG.

Figure 5: Simplified model of line with SAs at points 1, 5 and 9.
However, depending on the input, output and penetration of the DG, and of the characteristics of the system, the increased voltage and power flow may vary and lead to problems of coordination and selectivity, as well as voltage fluctuations, creating an uncertainty for the operation of the system. Such situations could involve the need of resizing and replacement of protective equipment in various situations. In this context, it is possible to apply the concepts of SG and the installation of smart tools with measuring devices, control, sensing and communication to monitor the level of variation in the behavior of the system across the connection and disconnection of distributed generators. With the implementation of these smart meters, it will be possible to send the connection status of each generator for a central in order to minimize these uncertainties and design more robust protection systems, providing improved reliability and continuity of the operation of the EPS with DG.

Finally, it should be noted that the concepts and methods presented here can be used in other systems for modeling and designing the protection against lightning overvoltages, through the use of SAs in the presence of DG. Equally, the protection procedures carried out for the DL of this article would be applied to other electrical systems, if their electrical characteristics for sizing, allocation and quantification of SAs to be installed are evaluated.

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VII. REFERENCES

A greening energy positive tool for energy management in infrastructures and buildings of public use

Technical and Economic Assessment Framework for the Integrated Management of PV and EV Systems

José Javier García¹, Regina Enrich¹, Marc Torrent-Moreno¹
¹Barcelona Digital Technology Centre, Roc Boronat 117, 08018 Barcelona, Spain
{jjangarcia, renrich, mtorrent}@bdigital.org

Abstract—In order to enhance energy efficiency in buildings and their surrounding areas, the concept of current building management systems has been extended to include capabilities to manage distributed energy sources based on renewables, electric vehicles and demand response programs. The technical and economic impact assessment performed in two high-profile facilities of public use shows that economic profits and environmental impact reduction can be achieved in certain scenarios.

Keywords- PV, EV, OGEMA, buildings, energy, optimization

I. INTRODUCTION

Nowadays, buildings account for 40% of total energy consumption in Europe and generate 36% of Green-House Gases (GHG) [1]. Energy performance of buildings plays a key role in achieving the EU’s Climate & Energy objectives, namely a 20% reduction of GHG emissions, 20% energy savings and 20% share of renewables by 2020. In the long term, the EU goal of reducing greenhouse gas emissions to 80–95% below 1990 levels by 2050 [2] implies a higher energy efficiency in new and existing buildings and paves the way to zero-energy buildings. Energy efficiency must be taken into account in the whole life cycle of a building; not only must the construction sector face a revolution with the research in new materials, design tools and construction processes, but also the way energy is managed in buildings, and in a broader context in districts and cities, must change.

Technology will be an essential part of the solution to the decarbonisation challenge faced enabling building managers to handle the increasing complexity involved in facility management due to the addition of new elements such as distributed generation (DG), renewable energy sources (RES), electric vehicles (EV), variable tariffs and demand response programs (DR).

Building management has traditionally followed a centralized approach, where most of the systems within a building are monitored and managed from a central unit, e.g., a Building Management System (BMS). Yet, most of the BMS on the market do not include tools for the management of new devices and additional information or requirements such as DG, RES, EV, DR, variable tariffs, weather forecast, decision support tools for facility managers, etc. Aiming to cover this gap, BEAMS project is developing a Building Energy Advanced Management System integrating energy management of a myriad of heterogeneous systems in buildings and infrastructures of public use, both from a technical and economic perspective. Additionally, it includes a set of Greening Energy Positive Tools (GEPT) which integrate the management of Photovoltaic systems (PV) and EV, an Energy Efficiency Balance Score Card (EBS) and a Decision Support and Simulation Module (DAS) to support facility managers not only in daily operations, but also on the planning and maintenance of the infrastructure.

The whole BEAMS platform is being validated in two high-profile pilot sites: the Football Club Barcelona facilities in Spain and the University of Salento Campus in Italy.

This paper presents the GEPT approach followed in BEAMS project, detailing technical aspects and the first results obtained for its validation.

II. PV AND EV INTEGRATION IN BUILDINGS

BEAMS platform core element is an open interoperability gateway based on OGEMA [5] - an open software platform for energy management- that allows the management of diverse, heterogeneous energy sources and loads in a decentralized and autonomous way. Some of the systems are typically present nowadays in spaces of public use (e.g. public lighting, ventilation, air conditioning), some others are emergent and to be widespread over the next years (e.g. photovoltaic systems or electric vehicles).

BEAMS project proposes a decentralized architecture to extend current building management systems as illustrated in Figure 1. The main elements of the architecture are the open interoperability gateway OGEMA and the Facility Management Environment (FAME). A facility can include many OGEMA instances, each one controlling a set of devices. OGEMA includes different modules to interact with physical
devices as well as more advanced applications that allow facility managers to optimize load demand. The Greening Energy Positive Tools (GEPT) developed for the integrated management of EV and PV systems are examples of such applications. On the other hand, FAME will take advantage of the fine grained data obtained from several different OGEMA instances, to detect and optimize all systems within a facility according to the facility manager’s technical and economic goals.

Regarding the GEPT framework proposed in BEAMS, two applications have been developed, namely CHOP (Charge Optimizer) and PVOP (PV Optimizer). These tools are utilized in two different environments: real-time environment and simulation environment.

In the real-time environment, the GEPT main functionality is to locally balance the energy generation and consumption, scheduling the charge of EV, taking into consideration technical constraints, users’ preferences, and energy availability. At the same time, EV provides the facility with storage capacity to mitigate renewable sources volatility and better manage the rest of the facility loads. Advanced algorithms have been developed to achieve a high performance of these Greening Energy Positive Tools.

The purpose of CHOP and PVOP also running in the simulation environment is to better support the integration of Electric Vehicles and Photovoltaic systems and ease the assessment of their technical and economic impact in a facility. In this sense, they provide the tools for the facility managers to assess the impact of the current infrastructure already deployed as well as the assessment of the impact of introducing new infrastructures e.g. installing new PV panels or new EV charging stations.

BEAMS project GEPT framework proposed is illustrated in Figure 2.

### III. EV AND PV IMPACT ASSESSMENT

Different scenarios have been analyzed, taking into consideration the location of both pilot sites and the facility usage.

In the case of the football stadium facility, the impact of the deployment of charging points in the surrounding area of the facility for (i) a sport event scenario usage and (ii) employees usage (office building profile) has been studied.

#### A. Football match scenario

The FCB facility comprises a football Stadium, a basketball/handball court and an ice-skate rink among others. However, the events that attract the most people and most stress the facility, in terms of energy consumption, are football matches. Furthermore, football matches are rarely scheduled before 17:00, which is especially relevant to assess the impact of a PV installation.

As it can be seen in Figure 3, during a football match, the power usage in the facility reaches almost the installed power capacity of the facility for different energy access points. In such a situation, the deployment of charging points around the stadium will further stress the electric network, and it will require the installation of extra transformer stations. On the other hand, the presence of EV could be seen as a contribution to the storage capacity of the facility to help balance production and consumption. However, this scenario does not appear to be suitable for exploiting this feature due to the following facts:

1. a) The supporters remain in the facility on average 2-2.5 hours. The time span to make usage of the storage capacity provided by EVs is limited, especially if the State of Charge...
(SOC) of the battery when leaving must be higher than SOC at arrival. In other words, the users need their EV to be recharged to reach their destination, thus minimizing the management capacity. In a word, the only strategy that can be applied is “plug and charge”.

b) Batteries are useful to mitigate renewable sources volatility, namely PV production. Nevertheless, the matches are usually scheduled at prime time to reach high audience shares on TV, while peak solar production time are at about midday.

c) When exploring EV batteries as a support for demand-response scenarios or Vehicle-to-Grid configurations, it can be computed that 42% of the energy of 500 EV provided by a 24 kWh battery would be necessary to back-up the grid (notice the Stadium has a capacity of 100,000 seats) during a football match. That would allow users to travel about 40-45 km away from the Stadium, which would not be sufficient for most of them.

Even if the analysis shows that this scenario has a negative impact on the facility in terms of energy balance, it cannot be concluded that charging points should not be deployed. Actually, if the EV penetration rate increases as foreseen, it would be necessary to provide this service in facilities of public use such as a football Stadium. The challenge here is to define a business model which is economically profitable and technically feasible.

B. Office pattern scenario

Apart from the supporters coming to sport events, the facility is visited daily by administrative employees, management staff, cleaning and maintenance services personnel, among others. The schedule of a significant number of employees is similar to a standard office building. Although the analysis presented in this section is focused in FCB Office pattern scenario, most conclusions can be applied to a University Campus, like the Salento University Campus which is part of BEAMS research project.

The analysis is performed taking into account users’ behavior in terms of arrivals and departures, electricity tariffs, and dimensioning of EV and PV infrastructures. These are the hypothesis for the calculations:

a) Users are assumed to arrive at the facility between 09:00 and 10:00 and leave between 18:00 and 20:00 from Monday to Friday.

b) To simplify calculations, all EV are assumed to have the same characteristics. In particular, they require to increase their SOC in 30%, which means 7,2 kWh to be transferred for a 24 kWh battery.

c) Data from irradiation and temperature has been obtained from 2009 records for a meterological station close to the location. This information is required to calculate PV production. Calculations could be improved by taking into account data for a wider range period of time and considering potential effects of climate change.

d) The cost of energy coming from the grid has been calculated based on 3.0A electricity tariff in Spain. The tariff comprises 3 different prices depending on the hour of the day, the day of the week (workdays or weekends) and the season (they vary slightly in summer and winter). TABLE I. shows the tariffs that apply to a workday for Summer season.

<table>
<thead>
<tr>
<th>Period</th>
<th>Energy Cost (c€/kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>[08:00 – 10:00]</td>
<td>14</td>
</tr>
<tr>
<td>[10:00 – 16:00]</td>
<td>16</td>
</tr>
<tr>
<td>[16:00 – 24:00]</td>
<td>14</td>
</tr>
</tbody>
</table>

TABLE I. **Tariff 3.0A for a Summer Workday**
Figure 4. Annual distribution of energy source for a 10-EV scenario

Figure 5. Profit study for 10 charging points in an existing installation for different tariff fees

Figure 6. Profit study for 50 charging points in a new installation for different tariff fees

Figure 4. shows that the mix of energy sources does not remain constant all year long. The results have been obtained simulating the energy potentially produced by a 50 kWp PV installation located in FCB and the energy required by 10 EV coming to the facility according to an office pattern schedule. The variation in the total amount of energy required monthly is not a seasonal effect. In fact, it is caused by different workday-weekend count for different months. By contrast, the energy import from the grid follows a seasonal pattern: in winter months the PV production is lower, thus requiring the purchase of more energy from the grid. Since cost per kWh for PV production is lower than that bought to the grid, recharge of EVs will be scheduled to use as much solar energy as possible. Should solar energy be insufficient to supply all EV demand, the recharge will be scheduled in P2 periods (medium prices in 3.0A tariff).

Although nowadays many cities offer EV recharge service free of charge to promote EV penetration, this measure is not sustainable and, in the future, it will have a fee attached. Using the assumptions presented above, the profitability of two different charging point installations has been analyzed: (i) a 10-EV charging point deployment in a parking lot not requiring any further works or equipment apart from the sockets and (ii) a 50-EV charging station requiring additional investment to extend electric network infrastructure. The details for both cases can be found in TABLE II.

<table>
<thead>
<tr>
<th>TABLE II. COSTS FOR AN EV CHARGING INFRASTRUCTURE</th>
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</thead>
<tbody>
<tr>
<td>Costs</td>
</tr>
<tr>
<td>EV infrastructure</td>
</tr>
<tr>
<td>10 charging points In a parking lot</td>
</tr>
<tr>
<td>50 charging points In public area</td>
</tr>
<tr>
<td>Charging points acquisition and installation</td>
</tr>
<tr>
<td>Transformer station, junction boxes, cabling, rectifiers</td>
</tr>
<tr>
<td>Operation and maintenance costs (per year)</td>
</tr>
</tbody>
</table>

An economic study taking into account a discount rate of 12 % for Net Present Value (NPV) calculations has been performed for different charging tariffs fees. For an infrastructure of 10 charging points in a parking lot, the NPV reaches a positive value for 0.35 €/kWh charged to facility users charging their EVs. As seen in Figure 5, if users pay a tariff similar to the price of electricity in households (0.19 €/kWh) the NPV is negative. A similar analysis has been performed for 50 and 100 charging points in a similar infrastructure, achieving similar results. On the other hand, if the deployment of an EV charging infrastructure requires further investment in electric network extension and civil works (such as the situation of installing charging points in a public area, in the street), the NPV remains negative while the tariff to recharge the EV is under 0.50 €/kWh, as shown in Figure 6.

Since the cost for a user to recharge their EV at home is significantly lower than recharging it in public EV recharging infrastructures (according to the analysis performed), the service should include some added value for them, such as parking facilities or recharging from green energy. New
business models need to be developed to make these infrastructures profitable.

IV. CONCLUSIONS

The main conclusions that can be derived are the following: i) the use of energy storage devices increases the efficiency of PV installations; ii) to mitigate the costs involved in the purchase of batteries, EVs appear to be a promising option.; iii) synergies should be found between all the stakeholders involved (facility managers, utilities and users of public infrastructures) to find win-win solutions. Finally, it is also worth mentioning that the environmental impact is an important factor to be taken into account while performing an impact assessment.

REFERENCES

Potential of Biofiltration for VOCs and Odor Emissions Control in African and Caribbean Countries

J. Perez, M. Reiser, and K. Fischer
Department of Solid Waste Management and Emissions
Institute for Sanitary Engineering, Water Quality and Solid Waste Management, ISWA
Stuttgart, Germany
Principal Author’s e-mail: j.arilexis@gmail.com

Abstract— Odors and volatile organic compounds (VOCs) are typical products of industrial processes that may cause nuisances and potential environmental threats. Biofiltration is a mature technology that employs a biofilm and a water layer to eliminate odorous compounds and several pollutants in the exhaust gases. It has demonstrated to be economically and technically efficient. No publication was found regarding the utilization of biofilters in African and Caribbean countries (AF&CA); therefore, the purpose of this research was to assess the potential of biofiltration to be established in these regions. After an exhaustive literature review and the utilization of an online survey, several outputs regarding its potential to be implemented in these regions were found. Results indicate that South Africa and Nigeria represent the most feasible countries for a prompt establishment. In the case of the Caribbean countries, in the Dominican Rep., Jamaica and Trinidad and Tobago emission targets for some VOCs in particular industrial sectors were found. However, in the case of Cuba this information was very restricted. The preliminary survey indicated that people recognize there are problems with odors, though, biofiltration was practically unknown by the participants. The results of this research indicate that Biofiltration is an emission control technology that has considerable applicability in both regions and its introduction will benefit remarkably several productive sectors in order to enable them to comply with regulations, and towards further implementation of sustainable technologies for the protection of the environment, while fostering improvement to human health.

Keywords— biofiltration, biofilters, odor, VOC, African, Caribbean, emissions control.

I. INTRODUCTION

As population enlarges, increases the competence for land uses and possible problems may arise due to the nuisances that the proximity to odor/pollutant emitting sources with households may generate. In order to protect the environment and assure a certain air quality, governments have established legislative regulating structures, by assigning institutions and designating standards to limit the generation of polluting substances and the emission of air pollutants [1]. VOCs may be originated from chemical mechanisms, solvent use, petroleum processing and other sources [2], [3].

While odors are generated from livestock, food processing industries, landfills, waste water treatment plants, among others [4]. Odors may not cause serious diseases, however, their persistence causes nuisances to sensitive people [5]; and concerning VOCs, they may be precursors of pollutants that degrade the ozone layer [6]; thus waste gases are to be treated.

The purpose of this research is to assess the potential of biofiltration to be established in African and Caribbean countries (AF&CA) since there is no publication in this matter in the mentioned regions. To make possible this analysis, the approach consisted on an exhaust literature review about the state of the art of biofiltration and then, about the existence of regulations and possible emitting sources in these regions. It was also considered the availability of the biofilter materials and possible air pollution control services. Besides, a survey was done in order to assess the awareness of inhabitants about the use of technologies to control air pollutants.

II. BIOFILTERS FOR WASTE GAS EMISSIONS CONTROL

Biofiltration is a technique that employs a biofilm, containing a consortium of microorganisms in contact with water and the air pollutants; which by consuming the organic compounds present in the waste gases sustain their growth and simultaneously eliminate the content of several pollutants in the exhaust gases. It has been proven as a very efficient technique for the treatment of VOCs and odor emissions [7]. Among the main factors that influence biofiltration can be mentioned [2]: microorganisms, moisture content, temperature, oxygen content, pH and the biofilter medium. Fig. 1 exemplifies the principal components of a biofiltration system.

Figure 1. Scheme of a typical biofiltration system [31].

Extensive thanks to the sponsors: International Postgraduate Studies in Water Technologies scholarship (IPSWAT) and the Institute for Sanitary Engineering, Water Quality and Solid Waste Management (ISWA).
III. APPLICATION OF BIOFILTERS IN AFRICAN AND CARIBBEAN COUNTRIES

A. African Countries

1) South Africa

The government is configured in three independent domains which work interconnected to execute and supply directives that embrace air pollution control. The governmental sector is divided as national, provincial and municipal spheres [8]. The National Department of Environmental Affairs and Tourism (DEAT) is the controlling agent for environmental quality management. It supplies policies, standards and regulations to assure air quality in the country. Each one of its functions is described in the Air Quality Act. In terms of offensive odors, it is responsible to designate measures for their control [9].

The National Environmental Management: Air Quality Act (2004/2005), represents a new and advanced phase in respect to atmospheric pollution prevention. In this act, international best practices were considered, and more executive power is given to the local government in order to oversight and to manage the air quality and the compliance with the law [8].

In the governmental notice no. 248, Gazette no. 33064 of the South African Department of Environmental Affairs: “National Environmental Management: Air Quality Act (39/2004): List of activities which result in atmospheric emissions which have or may have a significant detrimental effect on the environment, including health, social conditions, economic conditions, ecological conditions or cultural heritage”[10] is compiled the national emission limit standards from South Africa in respect to VOCs, odors and chemical compounds of interest for biofiltration. It contains limit values for more than 8 industrial categories and subcategories.

- Case NATREF

Greeff [11] analyzed the VOCs emission control system of the National Refiners of South Africa (NATREF) in order to determine the efficiency of the plant. It was found that there were inappropriate VOCs emissions audit which causes a loss of three million rand per year, equivalent to 231,682.86 €/year, due to VOCs discharges.

The sources of VOC emissions at refineries are located into three principal zones, which should be constantly monitored to avoid leakages: fugitive VOC emissions (40 – 60% of total VOC emissions), VOC emissions from the wastewater treatment zone (10 – 15%), and, VOC emissions from storage tanks and product loading area (“tank farm”), representing 30 – 45% of total VOC emissions [11].

Regarding the availability of biofilter materials in South Africa, it was found that the following companies provide them: Blue Fig Landscaping, Hydro-Patch, Biz Afrika 1159 (Pty) Ltd, PurLec Hydroculture, The coir institute, Cactus Carbon (Pty) Ltd, Chemical Specialities Limited (ChemSpec), Organic Seeds, among others, including the Municipalities of Cape Town, Johannesburg, Breed River Winelands, Makana, Sol Plaatje.

Some of the companies that provide services in air pollution control include: Cactus Carbon (Pty) Ltd, SGS South Africa (PTY) Ltd., Ilithia Group / Emissions Abatement Solutions / Scion Technologies: representative of: MEGTEC Systems Environmental Products, WSP Africa: Protherm, Zululand Filters (Pty) Ltd, BBR Enviro Systems, Sg Plastic, among others.

2) Nigeria

Nigeria implements a very extensive environmental administration. The main governmental institutions aimed at protecting the environment, creating policies and their implementations are: the Federal Ministry Environment, Housing and Urban Development and the National Environmental Standards and Regulations Enforcement Agency (NESREA) [12].

The National Guidelines and Standards for Industrial Effluents, Gaseous Emissions and Hazardous Waste Management in Nigeria (1988 No. 58) (publication of 1991) [13], stipulated by decree in 1988 at the time, by the Federal Environmental Protection Agency; contains all the emission limits standards in regards of waste waters and gaseous emissions from different sources. Under the section: “National Effluent Limitations and Gaseous Emissions Guidelines in Nigeria for Specific Industries” are listed the different activities and emission limits.

In this standard, there are 10 industrial sectors regulated. In some sectors there is no regulations in terms of emitted substances, however, the law recognizes there is a problem with them. This is the case of odors, for example in the following sectors: agricultural chemicals (odors from meat packaging, fish processing, coffee roasting, starch manufacturing and rendering some solid wastes); plastics and synthetics (Volatile organics hydrocarbons); tannery (particulate odor in boiler emissions, odor from plant processes). The waste waters from tanneries and textile mills were considered as odor emitters, but there are no limit values.

- Case of Ibadan Oyo State

Ibadan is the capital city of Oyo state in Nigeria. It is positioned in the geographical coordinates 3 54 E and 7 23 N. This is the second largest and most urban city in southwestern Nigeria. Obayelu [14] did an investigation about the economical and environmental impact of odor emissions from mechanically ventilated livestock building in this state, by employing surveys to people working with poultry, pig and goat/sheep farms. People explained that the odors from livestock produce the following effects on them: headaches, nausea, reflex nausea, gastrointestinal distress, fatigue, eye and throat irritation, shortness of breath, runny nose, sleep disturbance, inability to concentrate and typical stress reaction [14]. The same author offers a list of more than 14 options to reduce and avoid the generation of odors in farms, including the employment of biofilters.

The following companies provide biofilter materials in Nigeria: Aduayagada Investments Limited, Crystal Produce & Projects Merchants L.T.D, Global Sterling Products Limited, Bulwark associates Nigeria Ltd., among others. Regarding the companies that provide services for air quality control, the
following are listed: SGS Inspection Services Nigeria Ltd., MEGTEC Systems Environmental Products and WSP Group SA (Pty) Ltd.

3) Ghana

The Minister of Environment, Science and Technology is the governing institution in matters of environmental issues. It operates by the enforcement of the Environmental Protection Agency (EPA). After its formulation were conferred functions of compliance, enforcement and control in environmental aspects [15]. The Environmental Protection Agency Act of 1994, act 490 presents all the legislative functions of the EPA in terms of environmental enforcement, compliance and control, as a way to reach the National Environmental Policy in Ghana [16].

- Case of Sunyani Abattoir

Inhabitants of the community Nana Bosoma Central Market, in the nearby of the Sunyani abattoir, have presented several complaints to the environmental agency in Ghana and even to the press, the Ghana News Agency (GNA). They complain about the bad smells originated from this place, due to the bad management and lack of hygiene [17].

This abattoir was installed in 1972 and since then, no reconstruction has been made. Local environmental responsible, Mr. Simon Opoku, Sunyani Municipal Environmental Officer agrees on the deplorable situation going on there, however, still no real changes have been made [17].

Regarding the availability of biofilter materials; the following companies were identified, which provide several of the biofilter materials: Accra Compost Plant, Decol! Sustainable farming, IBIC Ghana Limited, Tri-West Ghana Ltd, Purity Gold Ghana Limited, Timber solution ltd, African Center for Enterprise Development (ACED), among others. A company that provides services in VOCs and odors monitoring is: SGS Ghana Limited.

4) Kenya

The Ministry of Environment, Water and Natural resources is the directive institution in matters of environmental quality and pollution prevention. Some of its functions are: elaboration of policies directed at protecting the environment, to lead a sustainable management of natural resources, to promote the research and spread information regarding land resources and geology, to control and organize environmental activities and prosecute the compliance of environmental regulations and guidelines [18].

The Environmental Management and Coordination Act, 1999, is the mandate for the establishment of the National Environment Management Authority (NEMA). This represents the action section of the mentioned Ministry of Environment, Water and Natural resources [19].

In this act there is no information regarding the emission limits, however it indicates the creation of local organizations as enforcement institutions and receiver of issues regarding pollution and environmental problems. These institutions are [19]: the Provincial and District Environment Committee, and the Public Complaints Committee

- Planning of a Mini Leather industry in Isinya Town

In 2012, the Kenya Leather Development Council executed an environmental impact assessment with the coordination of the company Umwelt consults, in order to determine the potential impacts of the establishment of a mini leather industry in the Isinya town and district; under the specification of the Environmental Management and Coordination Act (EMCA) of 1999 [20].

The council had a budget of Kenya Shillings Ten Million (KES. 10, 000,000.00), equivalent to circa 90,000 €, for the construction of the tannery. Moreover, a local organization, the Maasai Rural Training Institute (MRTI) supplied 2 acres of land for the location of the mentioned tannery [20].

As part of the environmental impact assessment, the generation of odors from the tannery was considered. However, the suggested control method was mainly by the application of chemical compounds. For the case of H\textsubscript{2}S, the following substances were cited: bleach, sodium hypochlorite, calcium hypochlorite and ferric chloride. After the identification of possible air pollutants from the tannery process, some air pollution control techniques were listed, however, biofiltration was not considered among the BAT [20].

Some of the companies that provide biofilter materials are: CPZ, Ltd., Olarro, Kocos Kenya Ltd., TakaTaka Solutions Ltd., Live-Ex Resources, Envirosan International Ltd. Among the companies that provide air pollution control services in Kenya are: SGS Kenya Limited, MEGTEC Systems Environmental Products, among others.

B. Caribbean Countries

1) Dominican Republic

The Ministry of Environment and Natural Resources is the governmental institution responsible of the protection and conservation of the natural resources in the Dominican Republic. This is also responsible of the prosecution and penalization of any inappropriate action that acts against the sustainable management of resources and the established laws.

In the Dominican Rep., the regulating policy in the field of environmental protection is the General Law of Environment and Natural Resources, no. 64-00, stipulated on August 18th, 2000. This law describes the functions of the mentioned Ministry, and incorporates aspects of sustainable management of natural resources, situations of crime against the environment and a more effective way of controlling pollution and protecting the environment. This law regulates in general VOCs, H\textsubscript{2}S and PAH from existing and new plants [21].

- Case of emissions inventory in the DR

In 2009, the Central American Commission of Environment and Development in conjunction with the Ministry of Environment and Natural Resources, developed a emissions inventory of seven selected air pollutants, including VOCs, generated from stationary sources, area sources and motor vehicles. The methodology employed was based on: direct measurements from sources, emission models (all of them elaborated by the US-EPA, such as: TANKS 3.1, LANDFILL, among others), interviews, emission factors (the source was the Air Chief Version 8) and material balances [22].
In the inventory, the annual VOCs emissions per source in the Dom. Rep. are: 119,794.6 ton/year VOCs and 30,836.5 ton/year NH3 from area sources; 437,730.9 ton/year VOCs and 882.9 ton/year NH3 from stationary sources. From all air pollutants emitted from the Dom. Rep., VOCs represent 32%. The main emissions of VOCs correspond to the industrial sectors of food products, beverages, elaboration of oils, fats and tobacco [22].

Some of the companies that provide the biofilter materials in the Dominican Rep. are: Agroesa – Agro Espinar S.A., Exportadora de Productos Ecológicos C x A, Asociación Dominicana de Agricultura Orgánica (ADAO), Laboratorios Sugar, Ferretería Hache, Agroforestal Línea Fronteriza, Ebanistería del Norte, C.xA. (EBANOR), among others. However, no information regarding companies priving services for air pollution control/ biofiltration was found.

2) Jamaica

The governmental authority in charge of protecting the environment in Jamaica is the Ministry of Water, Land, Environment and Climate Change (MWLECC). The administrative and operating institution is the National Environment and Planning Agency (NEPA). This was mandated since April, 2001. The main goal is to provide effective solutions to environmental problems, and to elaborate sustainable policies in the field [23].

The following are the departments forming NEPA which execute its responsibilities [23]: applications management division, Policy, planning, evaluation & research division, corporate management division, legal & enforcement division and, integrated planning & environment division.

The Natural Resources Conservation Authority Act [24] is the mandate document for the establishment of the regulating environmental agency in Jamaica. It also indicates national standard limit values, according to different industrial sources. In terms of stack emissions standards; this law prescribes emission limit values and regulations for the most relevant industrial facilities, such as: mineral industries, fuel combustion, petroleum refining, waste management and inorganic chemicals. No information regarding odor emissions was found, however, the only sectors with limitations for VOC emissions were: waste treatment and petroleum refining [24].

The Jamaican regulations for air pollutants have been based on the American and Canadian air quality regulations. Some governmental institutions with responsibility with the environmental air quality have assumed a list of toxic pollutants, which include relevant VOCs substances, and indicated standard limit values. These are mainly applicable to new facilities or when significant changes are made to existing facilities. These limit values are compiles under the same law and as “Ambient air quality guidelines for priority air pollutants (PAPAAQG)” [24].

- Negril & Ocho Rios Wastewater Treatment Plants

The European Union has supported the construction and rehabilitation in 1998 and 2002, respectively of these two WWTPs in the tourist coastal towns of Negril and Ocho Rios. The investment accounted for more than 3,030,000.00 € via the 7th European Development Fund (EDF) (7 ACP JM 23/24), promoting the economic growth of this region [25].

In 2005, an assessment was undertaken in this installation in order to determine the status and efficiency of the plants. Several deficiencies were found and recommendations were made. Some of the installations to be installed by 2010 were: a hydraulic surge protection, a sludge thickener, and an odor filter. The operating agency is the National Water Commission [25].

Information regardind services for VOCs or odors control was not found, however, there are companies that provide the materials for biofilters. Among them: Info Tech Limited, Pimento Coal Jamaica Ltd., Evergrow Garden Center, Canco Limited – Ecowells Limited, among others.

3) Trinidad and Tobago

In Trinidad and Tobago, the principal institution related with environmental protection is the Ministry of the Environment and Water Resources (MEWR). The operating control agency is the Environmental Management Authority (EMA) [26]. The principal air pollution control policy is the Environmental Management Act, promulgated in 2000. In this act, EMA and its administrative structure is designed, joined with its functions. This act constitutes a legal framework for the protection of the environment and its management. In the chapter 35 - 05 of the Environmental Management Act are described the air pollution rules, the governmental authorities, fees that need to be paid in case of infractions and the national emission standards [27]. In this regulation, more than 10 VOCs are regulated.

- Case of air quality in TT

In order to determine the air quality status in Trinidad and Tobago, in 1999 an air quality assessment and modeling was conducted by the Town and Country Planning Division (TCPD) on representation of the Government of the Republic of Trinidad and Tobago (GORTT). Results indicated that the main anthropogenic sources of VOCs in this country are from manufacturing, including petroleum refining 25% and ammonia 41%; followed by the sector transportation 21%. While, the principal sources of ammonia emissions come from its manufacture. In this study, it was also appointed non-point sources of air pollution complaints, in which odors was included. These complaints originate from communities, and individuals, due to malodors from sewage treatment plants, dumps, landfills and burning of these [28].

Similarly, in Trinidad and Tobago, information regarding air pollution control/biofiltration services were not found. Nevertheless, the biofilter materials are available. Som e if its distributors are: Plant Doctors Trinidad, Rodulfo Lumber Supplies, Meat Plus Ltd., Tracmac Engineering Ltd., among others.

4) Cuba

The Ministry of Science, Technology and Environment (CITMA) is the governmental coordinating institution responsible of executing and prosecuting the state norms in terms of sciences, technology and environment and for the use of nuclear energy, thus, there is a sustainable integration among these sectors [29].
It was not found information regarding national air quality standards that regulate odor or VOCs emissions. However, it was found regulations for typical greenhouse gases (Muñoz, 2005). In the following website can be found all pertaining laws, policies, guidelines and governmental statements in Cuba: http://www.medioambiente.cu/legislacionambiental/leyes.htm

- Case of sugar cane industry

This is a very important economical sector in Cuba. Annually, 10 to 20 million tons of bagasse are produced. Moreover, this industry releases large quantities of air pollutants as well as VOCs to the atmosphere, like ethanol, which is accounted to be 600 tons released per year in Cuba. In order to reutilize the byproduct generation of bagasse and determine the potential efficiency of this material as biofilter bed, a group of researchers developed an experiment for this context [30].

For this experiment, the type of biofilm was selected particularly to remove ethanol; the yeast specie Candida utilis was employed to propagate on the bagasse used as filter bed. The bagasse showed the advantages of being porous and compacted; some mineral salts were incorporated, such as ammonium nitrate to help the efficiency of the yeast [30].

Results indicated that this yeast can assimilate up to 250 g ethanol / (m$^3$h) in optimal conditions. When bigger doses want to be incorporated, it should be done moderately, the same with the nutrient supply. Otherwise, there will be an overload of substances and the elimination efficiency will decrease significantly. Finally, it was suggested to continue the research at an industrial scale, since a successful result can benefit greatly this sector [30].

Biofilter materials are available in the following companies: Empresa Azucarera “Dos Ríos”, Maprinter, ALCARBON S.A., RX bricolatges sl, among others. Information regarding services for biofiltration was not found.

IV. RESULTS OF THE SURVEY

In order to gather information regarding the impression of inhabitants about the status of air quality regulations and potential of establishing biofiltration in their regions, an online survey was developed. The survey was running for 1 month, and was designed with the Google documents for spread sheets application. It comprised a list of 20 questions regarding: governmental institutions, laws, description of odor problems, knowledge about biofilters, techniques used to control odors, availability/prices of biofilter materials, among others.

It was considered 61 African countries and 28 Caribbean Countries. The link of the survey was posted in online regional groups and also distributed by direct requests. In total, 92 responses were received. 70% of the participants came from the Caribbean region, while, 30% of the participants represented the African region. Fig. 2 indicates the main sources of odors in African and Caribbean countries, according to the participants of the survey.

V. CONCLUSIONS

From the four African assessed countries, South Africa and Nigeria represent the most feasible countries for a prompt establishment of biofiltration as a convenient technology for the treatment of waste gases. In these countries are present modern air quality regulations and practical national emission standards that control VOCs from almost all industrial sectors. Nevertheless, no clear policies regarding odor emissions control still exist. In all of the evaluated African countries exist consulting companies that provide services for the measurement and monitoring of VOCs and odors. In the Dom. Rep., Jamaica and Trinidad and Tobago, emission targets and limits for some VOCs in certain industrial cases were found, however, in the case of Cuba, this information was very restricted. In the Caribbean countries, most of the typical biofilter materials were also found at affordable prices, some could be found even almost for free. From the survey, people recognize that there are problems with odors, especially emitted from waste waters, industry and biological solid waste, nonetheless, few information regarding control techniques was offered. Biofiltration was practically unknown by the participants. Most of the people corroborated the existence of biofilter bed material in their countries. The results of this research indicate that this technology has great applicability in these regions and its introduction will benefit enormously, towards the protection of the air quality, while fostering improvement to human health.
REFERENCES


[10] National Environmental Management: Air Quality Act (39/2004); List of activities which result in atmospheric emissions which have or may have a significant detrimental effect on the environment, including health, social conditions, economic conditions, ecological conditions or cultural heritage” from march 2010, act no. 39, part of the Air Quality Act from 2004.


Session 3: Green Computing, Operation, Optimization and Servicing

Nine Lessons Learned From a Green Building Testbed: a Networking and Energy Efficiency Perspective
(Authors: Jianli Pan, Raj Jain, Subharthi Paul)

Tone Model Enhancement for Low Complexity Tone Recognition
(Authors: J. Chaiwongsai, W. Chiracharit, K. Chamnongthai, Y. Miyanagay, K. Higuchiz)

Optimization of Unstable Multihop Wireless Communication Networks with Digital Forensics
(Authors: Ryuya Uda, Katsuhiro Naito, Masaki Ehara)
Nine Lessons Learned From a Green Building Testbed: a Networking and Energy Efficiency Perspective

Jianli Pan, Raj Jain, Subharthi Paul
Department of Computer Science and Engineering
Washington University in Saint Louis
Saint Louis, MO, USA
{jp10, jain, and pauls}@cse.wustl.edu

Abstract—Buildings are significant contributors to global energy consumption and their energy efficiency is an important issue for future world sustainability. In our project, we built an energy efficiency research testbed in a USGBC (United States Green Building Council) LEED (Leadership in Energy and Environmental Design) "gold" certificated green building. We monitored the energy consumption and studied the recorded consumption data. In this paper, from a combined networking and energy efficiency perspective, we summarize the major 9 lessons we learned from the testbed and discuss what they mean for the future intelligent building designs and operation. We further broaden the scope to a series of locally inter-connected intelligent buildings with both energy consumption and renewable energy generating capability and study the issues in a microgrid scale.

Keywords- green buildings; energy efficiency; networking; microgrid; energy proportionality; sustainability

I. INTRODUCTION

The problem of energy consumption in building environments has been identified and investigated in many existing research efforts. One of them is described in the report [1] which gives approximate numbers and percentages that the building environments contribute to the total energy consumption in the United States. Specifically, it shows that buildings are responsible for almost 40% of the total energy consumption and 70% of total electricity consumption in the United States. They also contribute a huge part of total carbon emission which is directly related to the global climate and sustainability issues. Given the huge consumption numbers and the close relationship between human activities and building environments, it is very meaningful and necessary to study the energy consumption patterns in the building environments to research and look for potential methods to improve energy efficiency, reduce costs, and introduce effective operation and automation.

Hence, as discussed in our previous papers [2, 3], we built an energy efficiency testbed in a USGBC LEED "gold" certificated green building, which is a typical large office green building. It holds multiple departments and includes offices, labs, classrooms and conference rooms. It has adopted a series of "green" and sustainable designs and measures including more local material usage, advanced insulation design, rainwater collection in cistern, and renewable energy generators such as vertical axis wind turbines and solar panels.

We monitored the energy consumption of the building for a period of more than one year. Some typical data related to electrical, heating, and cooling energy consumption, and some data about renewable energy generated by the in-building generators were recorded. We carried out detailed modeling and analysis of the collected data and tried to find out the underlying energy consuming patterns. After that, we plan to design and implement novel methods and technologies to reduce energy consumption and improve energy efficiency by using networking and computing technologies. Particularly, we plan to design and implement a new smart-phone based location-aware automated energy control system for the green building testbed to optimize energy efficiency. We also envision multiple buildings with such systems can network with each other to create coordination and synergy in a microgrid [4] or even larger scale. More details of the data analysis, our system design, and introduction of the related works can be found in our previous papers [2, 3].

In this article, our primary focus is to summarize the lessons we learned from the testbed and to find potential implications for future designs and implementations of more intelligent and energy-efficient buildings. It is worthwhile mentioning that we are investigating from an energy efficiency perspective, though there can also be others related to building design, construction, material usage, and life-cycle sustainability. We also put the issue in a larger scale, i.e., in consumer-side power grid scale which is beyond a single building's scope. We believe that such perspective is important for a future world of smart grid.

The rest of this article is organized as follows. Section II is the detailed descriptions and discussions on the lessons we learned from the testbed. Section III is the conclusions.

II. LESSONS LEARNED AND DISCUSSIONS

In this section, we discuss the detailed lessons we learned and summarize them as follows:
A. Lesson #1: Centralized and fixed-pattern control leads to less flexibility and efficiency in conventional buildings

We investigated a series of buildings in our campus including our green building testbed and find that most of them incorporate centralized control designs for the subsystems such as HVAC (Heating, Ventilation, Air-conditioning, and Cooling), lighting, safety and security, and other appliances and subsystems. Multiple buildings share a centralized subsystem. Also, there is almost no interaction or synergy among these subsystems. For example, the running schedule of HVAC system usually does not work together with the safety and security system. It does not make use of recorded occupancy rate and activities information to adjust the running schedule, and the HVAC system almost consumes fixed amount of energy regardless of the real usage at different working hours. In other words, multiple subsystems run individually in a fixed pattern and there are very few or even no efforts to integrate them into a coherent system to gain better energy efficiency and realize real automated operation.

![Figure 1. Total electrical energy consumption traces of 48 hours for our testbed building](image)

Particularly, in our testbed, we recorded energy consumption data for almost one year and studied the energy consumption pattern. We studied both short-term and long-term correlations between two groups of parameters [3]: one is the energy consumption parameters such as electrical, heating, and cooling energy consumption; the other group includes environmental factors such as temperature and humidity. The data modeling and analysis results show very low correlations among these two groups of parameters. For example, some simple electricity consumption traces for 2 days are shown in Fig. 1. We can see that for these periods, the consumption toggles between two values and the patterns show little direct and clear correlation with the office and non-office hours. We discussed this with the electricity system maintaining technical staff of the building and found that the electricity provisioning systems offer relatively fixed pattern which includes redundant capacity and introduce little variation among different hours. We also find that this is not a special case, but a common method for most buildings in a campus.

To summarize the lesson we learn in this regard, we find that to enable the electricity consumption to be more correlated to the actual usage for better energy efficiency, we need to change the centralized control and fixed-pattern running mode into distributed control and dynamic switching among multiple running modes. Distributed control enables different building sections and subsystems to run as relatively independent systems and to adjust their own running policies and schedules to save energy based on actual usage or occupancy rate. Multiple running modes and dynamic switching among them make the energy provision match the actual demand actively, and the building system can be more flexible.

The economic potentials of doing this can be huge for several reasons. First, for single building, most of the energy waste in non-office or non-active hours can be avoided. Second, a large number of conventional buildings can benefit from it and the total economic benefits in a larger scale can be very significant. Third, distributed control and interaction bring more opportunities for various software and hardware vendors to work together, which potentially expedite the process of protocol standardization.

B. Lesson #2: Energy Harvesting cannot replace Energy Conservation

Energy harvesting means that the buildings are installed with renewable energy generators to provide alternative energy sources other than from the power grid. Typical energy harvesting facilities include solar panels, wind turbines, geothermal generators, biomass generators, etc. Energy conservation means that the building is installed with intelligent energy-saving devices or systems, or applied with specific policies to control the energy consumption and avoid waste. In the efforts of making buildings more efficient and reducing energy dependence to the outside power grid, these two mechanisms can usually collocate in a specific building.

Our testbed office building has solar panels and wind turbine on the roof. We found that the energy generated by the energy harvesting devices contributes less than 0.1% of the total energy consumption in this testbed building. Though the percentage can be a little bit higher for small and medium sized residential buildings, we find that it is not a good or cost-effective idea to just spend a lot of money installing as many solar panels as possible to cover the total energy consumption. Instead, we find that much of the energy in the building is wasted due to a series of reasons. For example, the centrally controlled and fixed running policy of the HVAC system leads to at least 50% of the total energy waste, especially in the non-office hours of weekdays and in the weekends. Also, lighting and other public electrical appliances in the buildings are mostly without intelligent and dynamical control mechanism which contributes to a part of the waste.

Comparing the two sides of energy harvesting and energy conservation, we find that given the current status of the energy efficiency in various buildings, it is reasonable to focus more on the energy conservation than energy harvesting efforts. There is significant room for energy conservation by reducing energy waste by applying some simple energy conservation policies or strategies. It is generally much cheaper than buying energy harvesting renewable energy generators to feed the gigantic demand and to cover the high energy consumption which includes a huge amount of wasted energy. In short, energy harvesting cannot replace energy conservation in our opinion.

C. Lesson #3: Building sections partitioning technology is necessary for building-level energy efficiency optimization

As shown in the data analysis results in our previous modeling and analysis work [3], for the building as a whole, it
is difficult to set up strong correlation between its total energy consumption and the environmental factors and occupancy rates. The reason we find is that building is a very complex system, and its separate sections and subsystems may demonstrate very diverse energy consumption patterns and have different correlations with related factors, and hence demonstrate various rooms for potential improvements. If we sum up all the energy consumption data and study them as a total number, we may lose a lot of useful information.

Thus, we coin a term of "deep building partitioning" technology to reflect our idea that we may study building’s subsections and subsystems separately. We can study the energy consumption of these systems and model their correlation patterns individually. It will enable us to know which sections or subsystems can be adjusted according to the actual weather condition and which sections or subsystems can be adjusted based on the real occupancy rates. Then we can apply networking and computing technologies to these subsystems to gain best results out of limited resources. For example, for the lighting subsystem, its real electricity consumption will be highly correlated with the occupancy rates in the building. Thus, we may apply related technologies to automatically turn off some or most of the devices during non-office hours or week-ends. Similarly, for HVAC systems, especially the small-sized HVAC systems for small and median resident buildings, their running schedules and strategies can be formed considering the weather conditions to achieve optimized energy consumption. Such ideas can be generalized to multiple types of buildings. Due to the diversity of buildings and various appliances in them, it is necessary to do such deep building partitioning based on each actual building before achieving optimized energy results for it. Generally, we divide this deep building partitioning technology into three key steps:

1. **Partitioned energy monitoring.** Building subsystems and subsections are monitored separately and their energy consumption is logged for offline modeling to find their correlation patterns for further consideration.

2. **Separate energy modeling and analysis.** The goal of this step is to find energy pattern for each subsystems and subsections that can potentially be adjusted to save energy.

3. **Applying changes using networking and other technologies.** Based on the modeling and analysis results of the step (2), we will know which subsystems and subsections can achieve best energy saving if we apply limited networking devices. Then we can devise the strategies for each subsystem or subsection to achieve optimization for a whole building.

4. **Lesson #4: Buildings should be designed and operated to be energy proportional**

   We know that buildings are complex systems, and it may be difficult to enable them to have simple and straightforward correlation with specific parameters. However, built upon the deep building partitioning technology, it is possible to enable the buildings to achieve best energy saving with limited resources. In other words, we may achieve "energy proportionality" to the actual usage or occupancy.

5. **Lesson #5: Enabling multi-scale (organization or user-level) energy proportionality using networking and computing technologies**

   A more aggressive goal than creating energy proportional buildings is to create multi-scale energy proportionality. It means that the energy proportional perspective can be realized at multiple granularities. In other words, by applying a series of networking and computing technologies, we may be able to allow not only building level energy proportionality, but energy proportionality for any scale, for example, a single user or a specific organization.
A typical example to achieve energy proportionality for a single user is applying networking technology based on smartphone with location-sensor to create a platform allowing users to automatically and dynamically control or adjust their own energy usage policy and profile across multiple buildings [2] in real time or according to their current locations. By doing this, users will be able to consume optimized amount of energy according to their real demand and usage. The individual user may have to follow the energy policies enforced or required by a larger affiliated organization such as a company or department in university. Hence, as long as individual users in a specific organization use applications like this, the energy proportionality for this organization can be achieved. Similar policy structure and policy enforcement can be applied to many other scales to achieve multi-level energy efficiency optimization goals. The details of how such energy saving policies can be negotiated and formed can be found in our previous system framework design paper [2]. A simple comparison of the concepts of energy proportionality in multiple granularities can be found in Table I.

Table I: Comparison of energy proportionality concepts in multiple granularities.

<table>
<thead>
<tr>
<th>Identify Major</th>
<th>Computer</th>
<th>Building</th>
<th>User</th>
<th>Organization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major</td>
<td>CPU, RAM, etc.</td>
<td>Key subsystems such as HVAC or electrical appliances</td>
<td>All components under the user’s control</td>
<td>All components under the organization’s automatic control</td>
</tr>
<tr>
<td>Keyidea</td>
<td>Dynamic running mode changes</td>
<td>Networked monitoring and control; Real time dynamic energy policy adjustment; Location based mode switching and control</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Keyenabling technologies</td>
<td>1. Multiple active running modes for CPU</td>
<td>1. Apply active running modes to key appliances</td>
<td>1. Direct monitoring and control</td>
<td>1. Multi-scale energy policies enforcement under its realm</td>
</tr>
<tr>
<td></td>
<td>2. Wide energy adjustment range</td>
<td>2. Allow dynamic control based on real usage</td>
<td>2. Dynamical adjustment based on location</td>
<td>2. Aggregate the building and user energy proportionality</td>
</tr>
</tbody>
</table>

There are several major benefits of realizing such multi-scale energy proportionality. The first one is the economic benefit. Apparently, a huge amount of energy waste can be avoided in multiple scales, and the total effects can be accumulated to a significantly large amount of energy savings for a specific region or country. The second benefit is that we can achieve better organization-based control and better representation of their existence. In other words, these organizations can design and enforce their own group energy-consuming policies and achieve optimized energy usage in their own territories. They can also play more important roles as high-level energy policy related strategy makers.

**F. Lesson #6: Actively involving occupants and stakeholders’ awareness and participation can make a huge difference**

With the proposed idea of involving smart mobile location based network control, we can greatly promote the broad awareness and participation in the energy efficiency efforts. People's awareness of the energy consumption issue and their behavior inside the buildings has huge impacts on the energy efficiency of the whole building. All the automated systems using advanced technologies work around and for the people or occupants. Neglect or unfamiliarity to the systems may lead to low effectiveness and efficiency of the advanced intelligent systems in the buildings. For example, most of people may not care too much about the energy consumption in their work places while on the contrary they may care more at their own homes. If the intelligent technology is too complicated for them to use, there will be a high possibility that the systems will be under- or unutilized. We summarize the following key factors that can influence the adoption of intelligent systems and hence energy efficiency inside buildings.

- **Awareness.** The occupants or the building owners may not know in detail how much energy they consume and how it is consumed. Hence, creating real-time data display applications for online access can make the stakeholders aware of the energy consumption before improvement measures are taken. A study by Oregon Sustainability Center shows that the commercial buildings’ energy consumption can generally be reduced by 10% if occupants are provided the energy usage information.

- **Sensitiveness.** Building stakeholders may have different degrees of sensitivity to the energy consumption issues. Methods associating such sensitiveness with the economic benefits may motivate them to take measures to actively interact with the intelligent systems in the buildings to improve the energy efficiency and save costs. Another study shows that providing users with in-home display of their real-time energy usage helps reduce the energy consumption by 15%. It demonstrates that combining the awareness and sensitiveness has a great potential in saving energy.

- **Participation.** Conventional buildings involve very little participation from the general population hence the energy policy and decision are out of the control of most of them. Intelligent systems with convenient methods encouraging the stakeholders’ active participation in the energy saving process can be very effective and fruitful. For example, smart phone applications [2] can be used to encourage such participation. Two green efforts of "Green Cup" energy-saving competition and "Green Lab Initiative" in Washington University have confirmed this.

To summarize, if we can actively involve occupants and stakeholders’ awareness, sensitiveness, and participation for the energy saving efforts through multiple policies, facilities, and activities, we can make huge difference in terms of reducing energy waste and improving energy efficiency for both individuals and organizational groups in multiple scales. It also means a lot for social sustainability.

**G. Lesson #7: Integrating social behavior and activities in sustainable education tools may have a huge impact**

Energy consumption is an issue not only about cost but also about environmental sustainability. Hence, saving energy and introducing intelligence into buildings also have social implications. Besides the long-term cost benefits, introducing intelligent building designs and certificates may help the stakeholders improve their public images in term of social roles and responsibilities. Future social network based applications
involve energy monitoring activities may help the energy efficiency efforts in a much larger scale and potentially have profound impacts.

To be more specific, we propose to take advantage of the smart phone and location service based idea [2] by designing and implementing a sustainability education tool with social network plugin (such as Facebook, Twitter, and Google plus) on the top of the smart-phone based energy monitoring and control application. A simple illustration of the concept is in Fig. 2. By creating a bridge between the energy monitoring/control modules and the social network module on the smart phone platform, and facilitating their interaction, we may be able to create extra incentives and motivations for every common energy user to know the energy consumption issue and participate in the global sustainability efforts, taking advantage of the fast and effective information propagation of the social networking applications. For example, a specific smart phone holder may post their energy profiles and energy-saving data through social network applications, influence other people's energy consumption habits, propagate good energy and sustainability concepts, and encourage everyone to participate in this global effort. Online social sustainability related activities may also benefit from such platform.

![Energy Monitoring and Control Module](image1)

**Figure 2. Bridging energy monitoring and control with social network applications**

There are two major forms that we can use the tool for wide-scale sustainability education. The first is through online social network dissemination and propagation as discussed above. By doing this, sustainability education can be carried out in every occupant’s real everyday life and their social behavior can affect those who are in their social network connections. The second form is through online or offline sustainability related competitions or social activities. The effects of competitions can be magnified by social media and everyone’s social behavior. The proposed idea builds upon our previous successful experience, and the new socialized idea may achieve even broader impacts. The potential for commercial applications is expected to be big if the proposed goals are realized and turned into real commercial products.

**H. Lesson #8: Create synergy among multiple intelligent buildings to enable optimization in a larger (microgrid) scale**

The importance of energy independence at multiple scales has been proven in the history of massive electricity blackouts internationally and their corresponding costs. The concept of microgrid [4] is to promote such energy independence. It promotes generating energy especially renewable energy (such as solar, wind, fuel cells, etc.) as near consumers as possible in a small-scale geographic area. The distributed energy generators provide a reliable and inexpensive alternative to the local consumers especially during peak time or even in the case of electricity blackout. The costs and risks of long-distance energy transmission and delivery are also reduced. Microgrids are very friendly to environmental sustainability due to the savings they introduce and the renewable energy generation they promote. Currently, microgrid concept is still in its incubation stage, and it is mostly restricted to the energy backup sources in small scale and lacks mechanisms and designs for smart dynamic allocation and scheduling among multiple sources.

For sustainability, we envision that in the future, buildings will not only act as sole consumers of the power grid, they will also become sources of energy, given the fact that more and more new buildings are now being installed with renewable energy generators such as solar panels, wind turbines, and biofuel-based energy generators. “Local generation, local consumption” policies can significantly reduce the energy dependence of the grids from different scales. By using smartphones and cloud computing technologies to allow microgrids to dynamically monitor, schedule, and allocate generation and consumption capacities, significant amounts of power transmission loss can be saved. With such optimization, peak energy demands can be reduced, potentially saving a lot of infrastructure investment in the construction of power plants. In short, it is of high significance in terms of sustainability to enable innovations at microgrid scale.

![Microgrid Networking and Control Structure](image2)

**Figure 3. A simple illustration of the multiple building microgrid networking and control structure.**

Hence, from a technical perspective, we identify several key components for possible innovations in this theme:

1. Network the buildings and create a central knowledge plane;
2. Optimized allocation and distribution of generated energy;
3. Smart prediction and balanced energy delivery.

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A conceptual illustration of this scenario is shown in Fig. 3. We propose to network neighboring buildings in a microgrid such that each building becomes an "Autonomous System" (AS) monitoring its own energy and interchanging real-time consumption and generation capacity information with neighboring buildings as well as a central knowledge server. Each building has a monitoring agent, a policy agent, an interaction agent, and a control system implementing agents that network together to achieve multiple functional optimizations. It virtually creates a central "knowledge plane" in a central server for the microgrid which is in charge of communicating with the agents of multiple buildings to collect real-time information through distributed networking and dynamic scheduling of the energy capacity of the microgrid. Individual buildings work in a distributed manner as well as interact with the central server without creating "single-point-of-failure" even when the central server is down. In Fig. 3, the top part is a network topology corresponding to the bottom physical building distribution. We can see that each building actually is a networked domain or an "autonomous system" which hides the inside networking structure to the outside. Every building is actually connected to the grid so even in case of faults or networking failure the building can continue functioning without any interruption. The central microgrid server and the agents in all the buildings can interactively work with cloud computing services for storage and application without introducing significant initial construction and maintenance costs.

On top of the networking topology and protocol problems, the energy efficiency optimization problem can be formalized and modeled as a computing optimization problem. Given all the constraints, we can use linear programming to solve such optimization problems in polynomial time.

I. Lesson #9: Synthesizing three dimensions related to the building concepts for future buildings

There are multiple dimensions of features relating to the concept of intelligent buildings depending on the major design goals. The three most important ones are:

1. Communication capability and intelligence;
2. Energy generation and conservation capability;
3. Material, physical design, environment friendliness, and sustainability.

These are shown in Fig. 4. If a building is designed and equipped with multiple intelligent technologies, then it is good in the first dimension. The general "intelligent building" concept falls in this category. Similarly, "net-zero energy buildings" [5] mostly focus more on the second dimension which is energy generation and conservation capability for the building to provide relatively stricter and more aggressive energy performance on an annual basis. Lastly, "green buildings" focus on the third dimension using more environment-friendly materials and designs to support the global sustainability and environment-protection call.

In our opinion, in terms of global sustainability and energy efficiency, future building designs should do better jobs in all three dimensions. In other words, all three dimensions should be synthesized in a single building, not only by design and construction, but also by the real operation of energy-generation and conservation and generation functional facilities, or the intelligent and networking systems installed and running in the building. For example, an intermediate design combining some of the three individual dimensions mentioned above is called "intelligent or bright and green converged buildings" which integrate features of dimensions (1) and (3).

Figure 4. Three dimensions of features related to building concept

III. CONCLUSIONS

Buildings are significant global energy consumption sources and their energy efficiency is important for future sustainability. In this paper, we presented our findings in analyzing a green building testbed and exploring a LEED (Leadership in Energy and Environmental Design) "gold" certificate building for energy efficiency research. In a combined networking and energy efficiency perspective, we summarize the major 9 lessons we learned from the testbed and discussed what they mean for the future intelligent building designs and operation.

REFERENCES

Tone Model Enhancement for Low Complexity Tone Recognition

J. Chaiwongsai∗, W. Chiracharit∗, K. Chammongthai∗, Y. Miyanaga†, and K. Higuchi‡
∗Department of Electronic and Telecommunication Engineering, Faculty of Engineering, King Mongkut’s University of Technology Thonburi, Bangkok, Thailand
†Graduate School of Information Science and Technology, Hokkaido University, Sapporo, Japan
‡Electronic Engineering, University of Electro-Communications, Tokyo, Japan

Abstract—This paper proposes tone model enhancement for low complexity tone recognition. The tone model reduces the number of input frames by estimating fundamental frequency \(F_0\) from only estimated vowel signals, called vowel magnitude difference function, vowel-MDF \(V_{MDF}\). Accordingly, it reduces \(F_0\) negative influence from neighboring syllables in continuous speech. We enhance tone recognition accuracy by more precise and low calculation vowel segmentation. This results in low complexity tone recognition making it suitable for portable equipment. In addition, the tone model is designed with parallel processing which results in real-time processing. The proposed method was tested and set by 40 Thai words, selected from voice activation for GPS systems and phone dialing options. The experimental results show 8.2% improvement in recognition accuracy, compared with the fixed vowel threshold. The tone recognition provides a 33.8% reduction in number of frames and 25.0% reduction in processing time, compared with using the entire syllable method.

Index Terms—Fundamental frequency \(F_0\), vowel-MDF \(V_{MDF}\), vowel segmentation.

I. INTRODUCTION

In non-tonal languages such as English and French, tone or pitch variation called intonation is used to express emphasis, contrast, and emotion [1]. Tonal languages such as Chinese, Vietnamese and Thai, use tone to distinguish word meaning. Each tone provides different grammatical meaning. When we apply traditional automatic speech recognition (ASR) to automatic tonal speech recognition (ATSR), the speech recognition system can provide low recognition accuracy, especially when words have the same phonemes but different tones. In order to improve ATSR recognition accuracy, tone recognition becomes an important part of ATSR.

Tone recognition is generally developed in isolated speech [2]-[3], and continuous speech. Continuous speech is more applicable for natural language which is typically used for communication. Different types of tone can be classified by using the trajectory of fundamental frequency \(F_0\) [4]-[5]. In continuous speech, the concentrated \(F_0\) is generally varied by the negative influence from neighboring \(F_0\), and recognition accuracy is reduced because of incorrect \(F_0\) features. To develop a highly efficient tone recognition, researchers should enhance the \(F_0\) contour so that it is the same as the ideal \(F_0\) contours of each tonal language and/or develop high recognition accuracy tone recognition.

Many researchers have tried to improve tone recognition accuracy by mathematical techniques such as a multilayer perceptron neural network [6], hidden Markov models (HMMs) [7], and Fujisaki’s model [8]-[9].

In order to enhance \(F_0\) contour, researchers may develop highly efficient syllable segmentation and also normalise \(F_0\) contour. There are many techniques for estimating pitch period in time domain and frequency domain. In frequency domain, harmonics tracking [10] indicates very high performance. However, it provides more complex calculation than in time domain.

The half-tone model [11] reduces the assimilation and declination effect from neighboring syllables by classifying \(F_0\) into first half and second half syllables. While it provides an efficient recognition accuracy, it still recognises tone from the entire syllable of \(F_0\) contour which is easily affected by adjacent syllables. Tone nucleus model and neural network [12] estimate \(F_0\) features without any negative influence from neighboring syllables by viewing only the tone nucleus. Due to the proposed tone model, it not only provides a clear linguistic meaning for the normalisation process but also shows explicit potentials for the detection of intonation structure from the target points. However, it finds \(F_0\) feature extraction, one of the highest calculation processes, from the entire input speech. In addition, it has to find the target \(F_0\) using the tone nucleus process as a feature of the tone recognition and therefore many processes are calculated.

This paper proposes a tone model enhancement for low complexity tone recognition. The tone model estimates \(F_0\) from only estimated vowel signals, called vowel magnitude difference function, vowel-MDF \(V_{MDF}\). This results in a reduction by approximately half in the number of input frames, compared with those used by the entire input syllable and also provides no adjacent syllable negative influence. Due to the reduction in frame number, the tone recognition provides low complexity. We also enhance tone recognition accuracy by more precise and low calculation vowel segmentation. The vowel segmentation provides high accuracy when we find the vowel threshold from the average energy of the entire syllable. In this paper, the average energy threshold calculation starts after the end of the utterance. This results in a processing time delay response. This paper finds the vowel threshold by adapting the average energy value. We assume that the
maximum energy value occurs in the middle frame and the threshold is half of the energy value of this frame. Since vowel signals can be estimated by time-synchronous calculation, the tone model can be processed in real-time processing. Due to the proposed vowel segmentation, the tone model provides more precision compared with using the fixed threshold value [13] and also can be appropriately applied to a wide variety of input speech. In addition, the tone model is designed with parallel processing to achieve real-time processing.

II. TONE MODEL ENHANCEMENT FOR LOW COMPLEXITY TONE RECOGNITION

The proposed tone model is divided into three processes: feature extraction, F0 estimation, and tone decision. Each process is explained as follows:

A. Feature Extraction

In the feature extraction process, the zero-crossing method [14] detects the voiced/unvoiced speech where the frame length is $N = 110$ (10 ms) and the frame shift is $N/2 = 55$ (5 ms). Every frame is applied with the Hamming window. In this paper, $j$ is the index of the $j$-th frame where $j = 1, 2, 3, ..., k$ and $k$ is the frame ending. The zero-crossing method is defined by

$$ Z(j) = \frac{1}{2} \sum_{n=1+(j-1)N}^{jN} |\text{sgn}(\hat{s}[n]) - \text{sgn}(\hat{s}[n-1])| $$  \hspace{1cm} (1)

where $j$ is the index of the $j$-th frame and the function of $\text{sgn}(\hat{s}[n])$ is defined as

$$ \text{sgn}(\hat{s}[n]) = \begin{cases} 1, & \hat{s}[n] \geq 0 \text{ and } \hat{s}[n-1] < 0 \\ 1, & \hat{s}[n] < 0 \text{ and } \hat{s}[n-1] \geq 0 \\ 0, & \text{otherwise}. \end{cases} $$

Voiced speech has low $Z(j)$ compared with unvoiced speech. Accordingly, when the calculated $Z(j)$ is lower than $T_v(j)$, this method decides that its frame includes voiced speech. In this paper, $T_v(j)$ is calculated from the minimum value between 40 and the silence threshold ($T_{sil}$). The value of $T_v(j)$ and $T_{sil}$ are given by:

$$ T_v(j) = \min(40, T_{sil}(j)) $$  \hspace{1cm} (2)

$$ T_{sil} = \overline{\text{sil}} - \sqrt{\frac{1}{N} \sum_{i=1}^{N} (s(i) - \overline{\text{sil}})^2} $$  \hspace{1cm} (3)

where $\overline{\text{sil}} = \frac{1}{Q} \sum_{i=1}^{Q} s(i)$ and $Q$ is set to 19.

Since the energy of a vowel signal is several orders of magnitude higher than that of a consonant signal, we segment the vowel signals from the frame which has an energy value that is greater than or equal to a vowel threshold $T_e(j)$. In this paper, we assume that the maximum energy value in each frame occurs in the middle frame ($j_e$). $j_e$ is set to the frame at $\lceil \frac{k}{2} \rceil$ where $k$ is the frame ending and $\lceil \rceil$ is the ceiling. First, the following energy value is defined:

$$ E(j) = \sum_{i=1+(j-1)M}^{(j+1)M} |s(i)|. $$  \hspace{1cm} (4)

The proposed threshold of the vowel energy value ($T_e(j)$) provides high accuracy with no accumulator operation as used in the average energy value. $T_e(j)$ is given as:

$$ T_e(j) = \frac{1}{2} E(j_e). $$  \hspace{1cm} (5)

A magnitude difference function (MDF) pitch extraction method is based on the calculation of speech waveform. We estimate $F_0$ by using only the parts of vowels, called vowel-MDF ($V_{MDF}$). We design this process by simple algorithms and thus its calculation costs are low. $V_{MDF}$ is applied to the selected frame $j$ in the previous section. Each $j$ frame calculates $V_{MDF}$ within a frame length $N = 256$. The following equation is applied to the selected frame:

$$ V_{MDF}(j, m) = \sum_{i=1+(j-1)M}^{(j+1)M} |\hat{s}(i) - \hat{s}(i + m)| $$  \hspace{1cm} (6)

where $\hat{s}(i)$ is an input vowel signal at the $i$-th sample and $m$ is a lag value.

The pitch period is estimated by selecting the minimum point of $V_{MDF}(j, m)$. In order to determine $F_0$ in the selected frame, $M$ used in the above equation is set to 128 and $m = [1, 2, ..., M]$.

B. F0 Estimation

The $F_0$ estimation process estimates the accurate $F_0$ from the value of $V_{MDF}(j, m)$. In order to eliminate the effect of the $V_{MDF}$ complex trajectory, the peak threshold ($T_p(j)$) is applied first to $V_{MDF}(j, l)$ where $l$ is the local minimum points, $L = [l_1, l_2, ..., l_p]$.

$$ P(j) = \frac{1}{p} \sum_{l=1}^{p} V_{MDF}(j, l) $$  \hspace{1cm} (7)

$$ T_p(j) = P(j) - \sqrt{\frac{1}{p} \sum_{l=1}^{p} (V_{MDF}(j, l) - P(j))^2} $$  \hspace{1cm} (8)

In Eq. (8), The value of $T_p(j)$ is defined as a pitch period threshold. The first term of $T_p(j)$ is the average value of $V_{MDF}(j, l)$ in the selected $j$-th frame. The second term of $T_p(j)$ indicates the variance of $V_{MDF}(j, l)$. Therefore, the threshold is given as the averaged lower bound of $V_{MDF}(j, l)$ variations.

The integer-valued pitch period is selected from candidate local minimum positions $l_i$ where $V_{MDF}(j, l_i) < T_p(j)$, $i = [1, 2, ..., n]$. If the estimated candidates $l_i$ show the positions of all local minima, $l_1$ is decided as the integer-valued pitch period of $V_{MDF}$. The $V_{MDF}$ pitch period ($P_v$) is defined by

$$ P_v(j) = l_1(j) \quad ; \quad l_1 > 0 $$  \hspace{1cm} (9)
Fig. 1 shows the example of vowel segmentation of the word “tät”; input speech (top), vowel signal by using fixed threshold at $j_v = 8$ (middle), vowel signal by using proposed threshold $T_e(j)$ (bottom)

Since the original speech is continuous-time signal, pitch period is estimated as a real number. In order to find the optimal pitch period, the integer-valued pitch period $l_1$ can be optimized by an optimal pitch period coefficient $l_0$ [13]. Because the signal statistics slightly change with time [14], this paper estimates $l_0$ by the association between the current samples and the past samples ($P_1$), and between the current samples and the consecutive samples ($P_2$) where $n$ is set from $1$ to $N = 256$ and $m = (j - 1)M$. A frame shift $M = 128$. The association between the current, past, and consecutive samples can be given by

$$P_1(j) = s(l_1 + n + m) - s(l_1 + n)$$

$$P_2(j) = s(l_1 + n + m) - s(l_1 + n + m + 1)$$

The $l_0(j)$ is defined by

$$l_0(j) = \frac{\sum_{n=1}^{N} P_1(j) \cdot P_2(j)}{\sum_{n=1}^{N} P_2^2(j)}$$

where frame length $N = 256$.

Finally, the fundamental frequency $F_0(j)$ is determined by the optimized pitch period. Namely, $l_0$ and $P_e(j)$ are the denominators used to provide $F_0$. The $F_0(j)$ is given by

$$F_0(j) = \frac{F_s}{P_e(j) + l_0(j)}$$

where $F_s$ is the sampling rate 11.025 kHz.

C. Tone Decision

The proposed tone model classifies tones by using a decision tree algorithm. There are certain features used in the decision tree. These are determined from the trajectory of $F_0(j)$ curve where $j = 1, 2, ..., k$ and $k$ is the frame ending. Three condition steps are considered to classify five Thai tones shown in Fig. 3.

Firstly, we determine the maximum $F_0$ of each syllable ($M_w$) as shown in Eq. (13), then the maximum $F_0$ of the first half syllable ($M_{h1}$) and the second half syllable ($M_{h2}$) are determined in Eq. (13) to Eq. (14). If $M_w$ is equal to $M_{h1}$, either a low or falling tone is a tone result. If $M_w$ is equal to $M_{h2}$, either a rising or high tone is a tone result. Due to a
mid tone characteristic, the $M_w$ of the mid tone can be equal to $M_{h1}$ or $M_{h2}$. Secondly, slope ($S$) in Eq. (17) is used to observe fall and rise of the $F_0$. Absolute slope ($|\delta|$), in Eq. (18), observes vertical and horizontal variation. If $|\delta| \leq 3.0$, only the mid tone is decided as a tone result. Finally, $F_0$ is divided into a first half and a second half syllable, then we compare the value of $F_0(j)$ to observe the initial and last parts of the both half syllables. The initial part of the first half syllable compares the values of $F_0(j)$ at $j = 1$ and $F_0(1)$ and $F_0(2)$. The last part of the first half syllable compares the values of $F_0(rd(k/2) − 1)$ and $F_0(rd(k/2))$ where $rd(x)$ shows the rounded off value of $x$. In the second half syllable, we compare $F_0(j)$ in the same way as the first half syllable. The initial part of the second half syllable compares the values of $F_0(rd(k/2) + 1)$ and $F_0(rd(k/2) + 2)$. The last part of the first half syllable compares the values of $F_0(k − 1)$ and $F_0(k)$.

$$\begin{align*}
M_w &= \max[F_0(j) : j = 1, 2, ..., k] \\
M_{h1} &= \max[F_0(j) : j = 1, 2, ..., rd(k/2)] \\
M_{h2} &= \max[F_0(j) : j = rd(k/2) + 1, \ldots, k] \\
S &= \sum_{j=2}^{k} (F_0(j) - F_0(j-1)) \\
|\delta| &= \sum_{i=2}^{k} |F_0(j) - F_0(j-1)|
\end{align*}$$

where $\max[x_i : i = 1, 2, ..., k]$ means that the maximum value of $x_i$ is selected among $i = 1, 2, ..., k$.

### III. Experimental Results

To evaluate the performance of a tone model enhancement for low complexity tone recognition, the evaluation is set by using the Thai voice command corpus database from the National Electronics and Computer Technology Center (NECTEC), Thailand. We test the tone model with 40 Thai words selected from voice activation for GPS systems and phone dialing options. Each word is sampled at 11.025 kHz and 16-bit quantization. The frame length and frame shift are 23.2 ms and 11.6 ms, respectively. In addition, the total processing time is tested by comparing the number of cycles of total operations processed in one frame with Altera Cyclone II EP2C70F896C6 running at 50 MHz.

The experimental results indicate the percentage improvement in frame reduction, recognition accuracy, and processing time. The percentage improvement is calculated by

$$\text{Percentage Improvement} = \frac{V_1 - V_2}{V_1} \times 100\%$$

where $V_1$ is the value given from the conventional method, and $V_2$ is the value from the proposed method.

The recognition accuracy is given by:

$$\text{Accuracy} = \frac{\text{number of correctly classified words}}{\text{total classified words}} \times 100\%.$$
TABLE I. Comparison between the number of frames in different vowel segmentation

<table>
<thead>
<tr>
<th>No.</th>
<th>Test Words</th>
<th>Entire syllable</th>
<th>Proposed Tc</th>
<th>Fixed Tc</th>
<th>No.</th>
<th>Test Words</th>
<th>Entire syllable</th>
<th>Proposed Tc</th>
<th>Fixed Tc</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>chye</td>
<td>73</td>
<td>42</td>
<td>39</td>
<td>21.</td>
<td>nzyu/sut</td>
<td>60</td>
<td>34</td>
<td>34</td>
</tr>
<tr>
<td>2.</td>
<td>mau</td>
<td>72</td>
<td>55</td>
<td>37</td>
<td>22.</td>
<td>ruyu/beep</td>
<td>74</td>
<td>50</td>
<td>26</td>
</tr>
<tr>
<td>3.</td>
<td>ssay</td>
<td>93</td>
<td>49</td>
<td>28</td>
<td>23.</td>
<td>ruyu/kuan</td>
<td>98</td>
<td>74</td>
<td>53</td>
</tr>
<tr>
<td>4.</td>
<td>tay/phæn</td>
<td>92</td>
<td>75</td>
<td>57</td>
<td>24.</td>
<td>ssat/shaan</td>
<td>88</td>
<td>48</td>
<td>28</td>
</tr>
<tr>
<td>5.</td>
<td>hæn/fæn</td>
<td>90</td>
<td>62</td>
<td>33</td>
<td>25.</td>
<td>hylat/phaap</td>
<td>83</td>
<td>36</td>
<td>29</td>
</tr>
<tr>
<td>6.</td>
<td>jian/riak</td>
<td>75</td>
<td>57</td>
<td>56</td>
<td>26.</td>
<td>tham/sam</td>
<td>88</td>
<td>55</td>
<td>25</td>
</tr>
<tr>
<td>7.</td>
<td>jut/sian</td>
<td>78</td>
<td>60</td>
<td>24</td>
<td>27.</td>
<td>phæn/tiu</td>
<td>88</td>
<td>62</td>
<td>54</td>
</tr>
<tr>
<td>8.</td>
<td>pit/ssay</td>
<td>82</td>
<td>49</td>
<td>23</td>
<td>28.</td>
<td>plæn/thian</td>
<td>102</td>
<td>77</td>
<td>44</td>
</tr>
<tr>
<td>9.</td>
<td>tøn</td>
<td>59</td>
<td>49</td>
<td>14</td>
<td>29.</td>
<td>pæ/thisi</td>
<td>85</td>
<td>56</td>
<td>45</td>
</tr>
<tr>
<td>10.</td>
<td>thát/pài</td>
<td>70</td>
<td>45</td>
<td>19</td>
<td>30.</td>
<td>seen/thian</td>
<td>85</td>
<td>66</td>
<td>42</td>
</tr>
<tr>
<td>11.</td>
<td>nh민on</td>
<td>72</td>
<td>57</td>
<td>55</td>
<td>31.</td>
<td>röt/tu/</td>
<td>40</td>
<td>21</td>
<td>14</td>
</tr>
<tr>
<td>12.</td>
<td>kwaan</td>
<td>56</td>
<td>36</td>
<td>22</td>
<td>32.</td>
<td>wän/seen</td>
<td>90</td>
<td>71</td>
<td>61</td>
</tr>
<tr>
<td>13.</td>
<td>khaam</td>
<td>72</td>
<td>38</td>
<td>32</td>
<td>33.</td>
<td>düan</td>
<td>43</td>
<td>31</td>
<td>25</td>
</tr>
<tr>
<td>14.</td>
<td>tát</td>
<td>25</td>
<td>18</td>
<td>25</td>
<td>34.</td>
<td>pee</td>
<td>49</td>
<td>34</td>
<td>17</td>
</tr>
<tr>
<td>15.</td>
<td>ph</td>
<td>31</td>
<td>22</td>
<td>9</td>
<td>35.</td>
<td>rip/ssay</td>
<td>72</td>
<td>51</td>
<td>34</td>
</tr>
<tr>
<td>16.</td>
<td>yâu/zuok</td>
<td>70</td>
<td>44</td>
<td>27</td>
<td>36.</td>
<td>plæn/thian</td>
<td>88</td>
<td>60</td>
<td>58</td>
</tr>
<tr>
<td>17.</td>
<td>sian</td>
<td>63</td>
<td>42</td>
<td>40</td>
<td>37.</td>
<td>thøo</td>
<td>59</td>
<td>23</td>
<td>21</td>
</tr>
<tr>
<td>18.</td>
<td>tem</td>
<td>60</td>
<td>35</td>
<td>11</td>
<td>38.</td>
<td>zien</td>
<td>52</td>
<td>25</td>
<td>24</td>
</tr>
<tr>
<td>19.</td>
<td>tøt</td>
<td>38</td>
<td>23</td>
<td>17</td>
<td>39.</td>
<td>nian</td>
<td>63</td>
<td>52</td>
<td>33</td>
</tr>
<tr>
<td>20.</td>
<td>chæn</td>
<td>80</td>
<td>33</td>
<td>14</td>
<td>40.</td>
<td>keem</td>
<td>63</td>
<td>56</td>
<td>26</td>
</tr>
</tbody>
</table>

TABLE II. Percentage improvement of tone recognition accuracy

<table>
<thead>
<tr>
<th>Tone Recognition Method</th>
<th>Recognition Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Autocorrelation with conventional vowel segmentation</td>
<td>81.9%</td>
</tr>
<tr>
<td>VMDF with conventional vowel segmentation</td>
<td>84.4%</td>
</tr>
<tr>
<td>Autocorrelation with proposed vowel segmentation</td>
<td>72.3%</td>
</tr>
<tr>
<td>Proposed VMDF with proposed vowel segmentation</td>
<td>77.3%</td>
</tr>
</tbody>
</table>

TABLE III. Comparison between average number of frames and total number of cycles per frame in different vowel segmentation

<table>
<thead>
<tr>
<th></th>
<th>Entire Syllable</th>
<th>Fixed Threshold VMDF</th>
<th>Proposed VMDF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average number of frames</td>
<td>77</td>
<td>32</td>
<td>47</td>
</tr>
<tr>
<td>Total number of cycles per frame</td>
<td>130,816</td>
<td>98,176</td>
<td>98,176</td>
</tr>
</tbody>
</table>
in $V_{MDP}$. It requires a greater processing time than in the proposed tone recognition.

**IV. CONCLUSION**

In order to design tone recognition for portable equipment, we need high recognition accuracy and a low complexity tone recogniser. This paper proposes tone model enhancement for low complexity tone recognition. The tone model recognises tone results from only the vowel signal of input speech instead of the entire syllable. This results in low complexity tone recognition. Due to low calculation cost, the tone recognition achieves real-time processing. In addition, the tone model improves tone recognition accuracy. We enhance vowel segmentation algorithm by the more precise and variable vowel threshold. We evaluate the tone recognition by 40 Thai words. The results show an 8.2% recognition improvement, compared with the fixed vowel threshold and 25.0% processing time reduction, compared with using the entire syllable.

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**REFERENCES**


Optimization of Unstable Multihop Wireless Communication Networks with Digital Forensics

Ryuya Uda  
School of Computer Science  
Tokyo University of Technology  
Hachioji, Tokyo, Japan  
uda@cs.teu.ac.jp

Katsuhiro Naito  
Faculty of Engineering  
Mie University  
Tsu, Mie, Japan  
naito@elec.mie-u.ac.jp

Masaki Ehara  
School of Computer Science  
Tokyo University of Technology  
Hachioji, Tokyo, Japan  
masaki@fpma.jp

Abstract—Multihop wireless network is in the minority among popular networks which are open to the public, although they have been often researched and proposed. One of the reasons lies in the problem in security. It is easy to protect message on communication in terms of confidentiality when all of the nodes are under the control of one user. In such case as sensor networks, malicious nodes are out of consideration. However, when a network is open to the public, a matter of security would be complicated since attacks and falsification might occur inside the network. Furthermore, detection and elimination of malicious nodes are difficult on an unstable multihop wireless network where nodes continuously move and some of them frequently join or leave the network. Therefore, in this paper, we propose a method for secure protocols to make an unstable multihop wireless network securely. The three elements in security are confidentiality, integrity and availability. In addition, we put a stress on authenticity and forensics on the network. The method contributes congestion control for unstable multihop wireless networks while keeping the network secure.

I. INTRODUCTION

Communication with Internet connection becomes a part of life for people. Trends of SNS (Social Networking Service) and video streaming service are being spurred on by smart phones. Therefore, ubiquitous communication environment must be required in big cities within a decade. Furthermore, communication in the environment must be wireless, seamless and hi-speed.

Smart phones require networks to be faster and to handle larger quantity of data than before. Wireless communication for phones is enhanced by smart phones and has evolved from 3G to LTE (Long Term Evolution) or 4G. However, communication speed is not so fast in a center of big cities because of congestion in wireless communication. The problem becomes more serious according to increase of the number of wireless communication devices. Since wireless communication on a bus or train, even or airplane, when there is a station of the wireless communication. In this case, congestion can be mitigated since each device connects to the nearest station with the lowest power while the station piles data packets of the devices in order to communicate with upper gateway. To combine short distance wireless communication such as Wi-Fi with long distance wireless communication would be one of the trends for ubiquitous communication environment within several years.

By the way, in the cases mentioned above, devices remain at the same place. Of course, devices move rapidly on a bus, train or airplane. However, the distance between a device and a station for wireless communication is constant. Therefore, devices relatively remain when they are observed from a sight of the station. If devices remain, short distance wireless communication is useless. The case would appear in communication of cars.

Therefore, we pay attention to multihop wireless communication. However, there are some problems especially in security terms. In this paper, we propose a method for unstable multihop wireless communication networks in order to reduce congestion while considering security. Especially, protection against denial is one of the most important matters for preserving digital forensics.

In chapter 2, related works are introduced. In chapter 3, details of the problems and proposed method are described. In chapter 4, consideration in terms of security is mentioned. Finally, in chapter 5, the paper is summarized.

II. RELATED WORKS

Said et al. mention about forensics on unsecured wireless network [1]. However, multihop is not considered in their research.
Kiess et al. introduce a toolkit for real-world experiments with wireless multihop networks [2]. However, they do not put a stress on security. Thus, the most of proposals of wireless multihop networks for real-world experiments put a stress on performance of the networks while security problems are sometimes ignored in the proposals.

Choi mentions about rate allocation for multipath routing in wireless multihop networks [3]. In his paper, security for multipath routing is considered. However, multipath routing is applied for enhancing protection against eavesdropping and against attacks by intruders. Of course, multipath routing is more secure than single-path routing, when a malicious node eavesdrops on messages communicated between correct nodes since eavesdropping of partial messages which are exchanged between only two nodes is useless for rebuilding original messages. However, it is not assumed that a large number of unspecified nodes join the network. Therefore, the research is not applied to real-world wireless networks as for smart phones, even if all of them are authenticated. On such real world networks, not only confidentiality but also integrity and traceability are required. On the other hand, our proposed method assures integrity and traceability.

Zhang et al. propose attack-resilient security architecture for multihop wireless mesh networks [4]. The half of their objectives is the same as ours. In this proposal, authentication which is based on public-key signature is adopted. Certificates in their method are based on X.509, but several parts of the certificate are cut since it is too large to use to build secure wireless mesh networks. They do not mention about practical examples of the networks in their paper. However, we guess their objective network is stable one since loads for authentication is not so heavy for a stable network in which a few requests are required for connection between nodes, even if public-key based authentication such as X.509 is fully applied to authentication of all nodes in the mesh. No evaluation of loads for authentication between nodes appears in their paper. However, the loads for authentication might be much heavy, if reconstruction of mesh is often required within a short term by moving nodes. On the other hand, in order to adapt the networks mentioned above, public-key based authentication and short length hash digests are combined for security.

Vijay-kumar et al. mention about the way of enhancing privacy and security in multihop wireless networks against traffic analysis [5]. They pay attention to eavesdropping on connections for multihop. However, integrity and traceability is never mentioned in their paper. Still worse, practical method is not described in detail.

Chen et al. propose trust of propagation and aggregation in wireless sensor networks [6]. However, the purpose of a method proposed in their paper is enhancing trust of sensor nodes which seem to be possessed by a correct owner. Therefore, the method is not suitable for a network which is open to the public.

Danev et al. propose hardware based identification for wireless sensor nodes [7]. However, sensor nodes described in their paper are assumed to be possessed by a correct owner. Therefore, the method is not suitable for a network which is open to the public.

Rengaraju et al. design distributed security architecture for multihop WiMAX networks [8]. Each node securely hops station by station in the architecture. The security architecture is similar to ours but the aim in the architecture is not enhancing security of messages on the network. Messages are not relayed node by node in their design.

Yang et al. introduce challenges and solutions in security on mobile ad hoc networks [9]. Several researches are explained and summarized in their paper, and one of them by Hu et al. [10] is similar to our proposal. In the research by Hu et al., a secure on-demand routing protocol for ad hoc networks is proposed and is named Ariadne. In Ariadne, oneway HMAC key chain is used for the purpose of message authentication. However, strength of authentication depends on one-way HMAC key chains. HMAC is suitable in a short period authentication but is not in a long term authentication since strength of hash function is particularly weaker than public-key signature. In contrast with Ariadne, public-key signature and hash function are combined in use. The latter is used for short term integrity with the consideration of performance of networks, and the former is used for long term forensics with the consideration of strength of certification.

Shajin-Nargunam et al. discuss a distributed security scheme for mobile ad hoc networks [11]. In their research, the fully distributed cluster based security algorithm is discussed. However, it is not assumed that a large number of unspecified nodes join the networks. Moreover, messages which are relayed on the networks are not certified. Shajin-Nargunam et al. also propose a cluster based security scheme for mobile ad hoc networks [12]. In the research, the fact that unspecified nodes join the networks is also ignored.

Thus, existing researches are not suitable for the enhancement of integrity and digital forensics on multihop wireless networks. Therefore, we propose a method with public-key signature based authentication for forensics while keeping performance in unstable multihop routing.

III. PROPOSED METHOD

The proposed method in this paper is separated into two parts. One is a method for message routing and the other is a method for message relay. In the former part in section 3.1, the way of building paths for routing messages is explained. In the latter part in section 3.2, the way of relaying messages securely is explained.

A. Method for Message Routing

Relation of nodes in our proposal is shown in Fig. 1. Nodes are cars in our proposal and they always move. Beacon is a station of wireless communication and often appears in ITS (Intelligent Transport Systems). Situation of this wireless network is different from either networks for smart phones or sensor networks.

On networks for smart phones, smart phones are directly connected to wireless stations such as Wi-Fi stations. Wi-Fi connection for smart phones would be more popular in the near
future since ordinary stations of communication carriers would be spoiled by congestion which is brought from the increase of the number of smart phones and their traffic. However, multihop routing in ad hoc networks would not be popular for smart phones since phones near a station has no merit in relaying packets from other phones. On the contrary, relays have a possibility of attacks in anonymity. The difference between networks for smart phones and for cars is simple. On the former networks, nodes rarely move. In other words, a node near a station need not relay packets from other nodes since the node can always connect the station directly. However, on the latter networks, nodes always move. In other words, a node which wants to refuse to relay packets from other nodes should be eliminated from the network since any node cannot keep a connection to the same station. Therefore, the strategy of multihop is necessary for networks in our proposal.

There are two channels in our proposal. One is B-channel which is used for making relays among nodes, and the other is D-channel which is used for transferring messages by the relays.

In Fig. 1, a node which wants to join a network sends a request message to nodes near it. At this time, the node behaves as a sender and it broadcasts SYN message. RP (radiation power) for the first SYN is set to the preset value. When nodes near the sender receive SYN and if they already join the network, the receivers reply a combination of SYN and ACK messages to the sender. If the number of receivers is zero, the sender resends SYN with gradually increasing RP. All of the receivers have MN (multihop number) which corresponds with the number of hops from a beacon. The sender chooses the receiver that has the youngest MN as a parent node of the sender. The sender sends ACK message to the chosen receiver and the value of MN of the sender is set to the value of MN + 1 of the receiver.

The construction of SYN from the sender is as follows. In Fig. 1, TIDs,CertTIDs , Time, (Sender ID)

\[
\text{SYN}(bc, TID_{s}, Cert_{TID_{s}}, Time), \quad \text{Sign}_{TID_{s}}(\text{SYN} || TID_{s} || Cert_{TID_{s}} || \text{Time})
\]  

(1)

**TID**: Terminal ID of sender

The construction of Cert_{TID} is as follows.

\[
\text{Cert}_{TID} = TID, \text{PubKey}_{TID}, \text{CAID}, \text{EXP}, \quad \text{Sign}_{\text{CAID}}(TID || \text{PubKey}_{TID} || \text{CAID} || \text{EXP})
\]

(2)

**CAID**: Certification Authority ID

**EXP**: Expiration

 Receivers which have MN reply a combination of SYN and ACK messages to the sender when they receive correct SYN. The construction of the SYN + ACK to the sender is as follows.

\[
\text{ACK}(TID_{r}, \text{CESK}(SYN || TID_{r}, TID_{s}, Cert_{TID_{s}}, MN, Time), \text{PE}_{\text{PubKey}_{TID_{s}}}(SK))
\]

(3)

**CESK**: Common key cipher encryption with key K

**PEK**: Public key cipher encryption with key K

**SK**: Session key

**TID_{r}**: Terminal ID of receiver

**PubKey_{TID_{s}}**: Public key of TID_{s}

After the sender chooses the parent node, the sender replies ACK to the chosen node. The construction of ACK from the sender is as follows.

\[
\text{ACK}(TID_{s}, \text{CESK}(TID_{r}, Time))
\]

(4)

When the parent node of the sender has MN which value is \( j \): node, the sender becomes \( j \) node. Every beacon has MN which value is set to zero. Procedure of making relays from \( node_{0} \) to \( node_{j} \) is shown in Fig. 2.

Every node finds its parent node with the step in Fig. 1 so that the steps from \( node_{0} \) to \( node_{j} \) make a procedure in Fig. 2.

Of course, every node always moves since it is a car. When a path from \( node_{0} \) to \( node_{j} \) builds once, it remains only within a short term. We think the term is kept in a fixed time. When a density of cars is low, each car can connect to a car far from it since RP is high. On the other hand, when a density of cars is high, RP is low. However, in this situation, each car might move slowly since high density of cars causes traffic jam. Therefore, our method can be applied without influence of density of cars.

**B. Method for Message Relay**

Messages from each node are relayed by other nodes as is mentioned in section 3.1. In our proposal, IP packets are encapsulated and encrypted so that IP header, other protocol headers over IP and payload are preserved. Plain text messages are exchanged between a node and a station. Other nodes on a relay do not confirm the contents of packets. They just confirm integrity of packets and store logs for forensics. The relay behaves as a tunnel between a node and a station.

Before encapsulation, a session key between a node and a station is exchanged. The exchange is seen the same as an encapsulated packet for other nodes on a relay. The session key is exchanged as follows.
\[ EP = TID, PubKey_{TID}, CAID, EXP, \]
\[ \text{Sign}_{CAID}(TID||PubKey_{TID}||CAID||EXP), \]
\[ PE_{PubKey_{TID}}(SK_j) \]  
(5)

\[ \text{EP: Encapsulated packet} \]
\[ SK_j: \text{Session key between a node and a station} \]

The session key is used like on TLS (Transport Layer Security). However, algorithm such as generating pre-master secret or master secret is not required since the session is kept within a short term.

After the exchange, \( EP \) for an encapsulated packet is generated as follows.

\[ EP = TID, CE_{SK_j}(TID, IP\text{-}header, \]
otherheaders(TCP,UDP, etc.), payload \]
(6)

\[ \text{EP: Encapsulated packet} \]

When the station has no \( SK_j \) for the node, received \( EP \) is one for key exchange. If \( TID \) which is extracted from \( CE_{SK_j} \) is not equal to \( TID \) which is attached at the top of \( EP \) although the station already has \( SK_j \) for the node, received \( EP \) is one for key exchange since the node has rebuilt a new relay.

Details of relays for uplink are described in section 3.2.1 and those for downlink are described in section 3.2.2.

1) \( \text{Relay for Uplink} \) - Before packets are relayed from a node to a beacon which behaves a wireless station, nodes are deployed as shown in Fig. 2. \( \text{Node}_0 \) is a beacon and \( \text{node}_j \) is a sender.

Packets are sent from the sender to \( \text{node}_{j-1} \) as follows.

\[ EP, r_{i,j}, \text{Hash}(EP||TID_j||SK_j||r_{i,j}) \]
(7)

\[ EP: i_{th} \text{EP} \]
\[ SK_j: \text{Session key for } \text{node}_j \text{ and } \text{node}_{j-1} \]
\[ r_{i,j}: i_{th} \text{pseudo random number by } j_{th} \text{ node} \]
\[ \text{DIR: Direction (uplink or downlink)} \]

The pseudo random number \( r_{i,j} \) is generated from a seed which is determined when a session starts, and the seed is not change in the same session. In \( r_{i,j} \), the same number appears until all of the numbers have appeared once, or the range for \( r \) is large enough.

Packets are relayed from \( \text{node}_{j-1} \) to \( \text{node}_0 \) as follows.

\[ EP, r_{j-1}, \text{Hash}(EP||TID_{j-1}||SK_{j-1}||r_{j-1}) \]
\[ j-1, \text{DIR} \]
(8)

\[ \text{Node}_{j-1} \text{ stores a relation between } r_{i,j} \text{ and } r_{j-1} \text{ in a log. The logs are corrected and signed by the secret key of the node every time when a pre-determined time passes.} \]

2) \( \text{Relay for Downlink} \) - Details of downlink are similar to those of uplink. Packets are relayed from \( \text{node}_0 \) to \( \text{node}_j \) as follows.

\[ EP, r_{0,j}, \text{Hash}(EP||TID_0||SK_0||r_{0,j}) \]
\[ 0, \text{DIR} \]
(9)

Hash functions which appear both in uplink and in downlink should have short length hash digest so that load of hash calculation is light. Hash digests cannot generate incorrectly with a short term session since cars always moves and a life of a session is not long. In addition, logs are signed with public-key signature within a pre-determined short term. Therefore, even if communication speed increases, load of signs by public-key signature is constant.

IV. \( \text{CONSIDERATION} \)

A. \( \text{Sniffing} \)

Logs on \( j_{th} \) node mentioned in section 3.2.2 are generated as follows.
The logs are signed by the secret key of $f_i$ when a session is closed or pre-determined time passes. The signed logs are sent to a station as one of the normal $EP$ packets. When illegal packets in which traces of attacks or threatening letters are included are found, $EP_i$ which corresponds to the packets can be found soon by only finding $Hash(EP_i)$ which corresponds to the $EP_i$ in logs. Of course, collision of hash digest sometimes occurs since the length of the hash digest is short in our method. However, a correct log for the packet which is wanted to be found can be specified since the packet is contained in the encrypted $EP_i$. Therefore, several rate of mishit can be ignored. $Hash(EP_i)$ behaves like index in our method.

Furthermore, malicious sniffers between nodes cannot distinguish logs from other ordinary contents since all of the packets transferred between a node and a station are encrypted. Moreover, malicious nodes on relays cannot erase logs by choosing logs among packets since all of the packets are encrypted. Of course, fabrication of a correct packet is easy for malicious node since the length of a hash digest is short and many packets for analysis can be collected. However, the fabrication is difficult with a short time. The fabrication must be finished correctly before a public-key signature is attached on the targeted log.

B. Digital Forensics

When traces of attacks or threatening letters are found later, a malicious car can be specified by investigation of $TID$. Moreover, the malicious car cannot deny the fact since the log is signed with public-key signatures of several correct nodes, and the sign behaves as forensics. Furthermore, the method is strong against attacks from a coalition. If malicious nodes make a team for generating a trap path to a station, they cannot keep the path secretly since cars always move and usual paths are always unstable. In addition, contents in a packet are encrypted between a node and a station. Therefore, fabrication of contents of other nodes is impossible.

The number $i$ must be too much long in formulas (7), (8), (9), (10), so that the same number does not appear within a short time. However, the length of $i$ does not seem to take so much cost in communication environment that we assume since relays by moving nodes are often reconstructed. If the number $i$ is over the length that is predetermined on a node, connection with the node should be reset so that the same number $i$ does not appear in the same session.

C. Detection of Liars

1) Impersonation: A station is not the same as a beacon as shown in Fig. 3. A station is the same as an authenticated web site with X.509 certificate, while a beacon is just one of nodes which transfer packets on wireless communication. Each node can obtain the certificate of any station which is authenticated by a certification authority through the session between the node and the station.

Any attacker cannot impersonate himself as a beacon. Only authenticated beacons can communicate with stations. An attacker cannot directly communicate with stations, since the attacker does not have TID which is authenticated by a certification authority. That is, no attacker can send logs of false communication to a station between a node and him without intermediate hops, even if he can make the logs. The forged logs would be detected by a beacon or other intermediate nodes, and then the attackers would be identified soon. Furthermore, in the method, all of nodes, even if attackers, have TID which is authenticated by certification authority. That is, there is no anonymity.

2) Black Hole by Attackers: If an attacker intentionally disposes of all packets from other nodes, he would be detected, since he must reply ACK packets while he disposes of data packets. If there is a node which behaves such as the attacker, it must be an attacker or a broken node. Anyway, the node would be eliminated from the network.

V. CONCLUSION

In this paper, we proposed a method for unstable multihop wireless communication networks in order to reduce congestion while considering security. Multihop in wireless communication is not practically used for usual networks although architectures and protocols for the communication have been often researched and proposed.

Multihop in wireless communication has few merits while it is always exposed to the menace of attacks from malicious nodes. Furthermore, there is no merit for a node which relays packets from other nodes since the relay raises chances of attacks from malicious nodes and it waist battery. Especially, it is better for the size of battery to be small for smart phones in terms of portability. Therefore, no one wants to relay packets from other nodes without merit.

In our study, we focus on communication for cars. A wireless network which is constructed by cars would be ad hoc type since high radiation power is required in order to make a connection between station and moving cars. Wireless communication with high radiation power causes congestion owing to the increase of the number of nodes. Still more, there is a merit to relay packets from other nodes. Mesh of the network is unstable since paths between a station and nodes are often changed by moving cars. In other words, every car has a chance to be a neighbor of a station, but it is not always the neighbor. A car which relays packets from other cars has a right to ask other cars to relay its packets when it is not near the station.

Figure 3. Relationship among stations, beacons and nodes.
Authentication with certificates is required on networks which are open to the public. Moreover, the certificates are generated by public-key signature algorithm since keys for making sessions cannot be shared between a large number of unspecified nodes. This is the difference between ad hoc networks by cars and sensor networks on which all of the nodes are possessed by the one owner.

In this paper, we propose a method which decreases the cost for integrity of relayed packets with short length hash digests while keeping authentication secure with public-key signature. The method assures that only authenticated nodes can join the networks and digital signature preserves digital forensics. Moreover, congestion is reduced by ad hoc networks. We think that the method is suitable for wireless communication networks for cars in the future.

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Sustainability Seal – How to Align the Brazilian Footwear Sector to International Requirements
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Study of Environmental Sustainability of Three Municipalities Using Emergy Synthesis
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Implementation of a Mobile and Stretchable Energy Production System Using P/V Cells
(Authors: M.G. Papoutsidakis, D. Piromalis, D. Tseles)

Valuation of investment projects in the context of sustainable development Real option approach
(Author: Krzysztof S. Targiel)
Sustainability Seal – How to Align the Brazilian Footwear Sector to International Requirements

Tereza C. M. B. Carvalho, Ana C. Riekstin, Gabriela A. Francisco
University of São Paulo (USP)
São Paulo, Brazil
{terezacarvalho, carolina.riekstin}@usp.br, gabi.amorozo@gmail.com

Ilse Guimarães
The Brazilian Association of Companies for Components for Leather, Footwear and Artifacts (Assintecal)
Novo Hamburgo, Brazil
ilse@assintecal.org.br

Abstract— The Brazilian footwear sector has faced high competitiveness and, as a result of its current positioning regarding quality and pricing standards, has lost market share in the recent years. Additionally, there is a great demand for sustainable offers in terms of industry processes and products. Given this reality, it is vital to push the footwear industry towards more sustainable practices allied with greater quality standards and lower prices when possible. This paper presents a proposal of a sustainable system of indicators, the Sustainability Seal, created for adding value and increasing the companies’ competitive advantage, aligning the footwear sector with international sustainability initiatives. The proposal presents 52 indicators classified into four dimensions (economic, environmental, social, and cultural) and three categories (obligatory, very important, and desirable). The Seal adoption is planned to be step-by-step, and, for that, comprises five maturity levels: White, Cooper, Silver, Gold, and Diamond. The set of indicators was defined based on a survey with footwear companies and on the alignment with other similar international initiatives. We also developed a software system, which allows self-diagnose for basic maturity levels (White and Bronze) and supports the auditing process by external certificate companies for advanced maturity levels (Silver, Gold and Diamond levels). The main contributions of this work are the development of a system of indicators that fully meet the needs of the footwear industry in Brazil, besides presenting a method that can be used to develop similar systems for other sectors.

Keywords- sustainability, indicators, footwear industry

I. INTRODUCTION

The Brazilian footwear industry, composed by leather, components, and shoes manufacturers is responsible, in conjunction with the textile, clothing and accessories sectors, for 6.8% of the country GDP, and for 16.5% of the total job positions, only behind the food and beverages industries [1]. In the world, Brazil is the third in shoes production, after China and India, and the eighth in shoes exports [2]. The sector has faced high competitiveness, especially from China and, as a result, is shrinking – which can be perceived by the drop in sales, in the number of jobs, and in exports in this sector [7]. To face this competitiveness, the footwear sector has been investing in design, new technologies and sustainability - the industry has as main impacting agents the use of potentially toxic substances and diversity of working conditions.

The awareness of the negative impacts of consumption patterns and the current production methods is increasing both in companies and in society. Companies like Wal-Mart are already requiring from its suppliers to produce more sustainable products [1]. Large industries, such as Nike and Adidas, have been working in the last years to use more sustainable components in their products.

In this context, performance indicators have been widely used to measure the attributes and results of a process, enabling the evaluation of the current situation regarding the business goals. These indicators are also used for communicating results [4] [5]. Indicators are able to provide a deeper understanding of the business main issues and to highlight important relations that are not evident using basic statistics [6]. In the last years, many sustainability evaluation systems were developed, such as the Dow Jones Sustainability Index, the Corporate Sustainability Index from BM&FBovespa – the Brazilian stock exchange, the Global Compact, the Global Reporting Initiative (GRI), and the ISO standards. This myriad of choices poses new challenges, especially for smaller companies, regarding which model or set of indicators to use. Further investments in processes and mechanisms to address these systems are generally costly, but necessary, by enabling the increase of competitiveness and by opening new markets.

In this regard, as a way to create value and increase the competitive advantage of the footwear industry, it is necessary to align the sector with international sustainability initiatives, a requirement to enable the inclusion of products of such companies in international markets, especially in Europe. This work proposes a new system of indicators (along with its development method), the Sustainability Seal, since the existing systems do not fully meet the needs of the footwear industry in Brazil. The remaining of the paper is organized as follows: Section II discusses the related work and existent systems of indicators. Section III discusses the methodology used to develop the Seal, along with the requirements of such a system. Section IV presents the Sustainability Seal details, followed by its validation in Section V. The concluding remarks and future directions are given in Section VI.

Sponsor: The Brazilian Association of Companies for Components for Leather, Footwear and Artifacts (Assintecal)
II. RELATED WORKS AND EXISTING SYSTEMS OF INDICATORS

Sustainable development is the one that meets the needs of the present generation without compromising the ability of future generations to meet their own needs [8]. It comprises economic, environmental, social and cultural aspects [9]. Any human activity affects the environment and there are reports that indicate that humanity has demanded 50% more of the natural systems than they can supply [10]. Despite the diffusion of sustainable practices in all supply chains and the increasing number of researches in the area of sustainability [11], it is still at an early stage in the vast majority of companies [12].

With the increasing concerns about environmental and social issues, many companies have implemented specific sustainability management systems in the last decade. These systems, however, are usually not integrated with the company management system. Therefore, the management of environmental and social pillars is usually disconnected from the economic management, and the economic contribution of these pillars is not clear [13]. Incorporate these aspects to the company’s Balanced Scorecard (BSC) is one way to bring sustainability together with the company’s strategy, giving them more than a qualitative bias. According to [13], there are three ways to integrate sustainability in the BSC: (i) integrate the environmental and social aspects to the existing perspectives; (ii) add a new perspective to consider these aspects; (iii) develop a specific scorecard.

Another way would be the use of a system of indicators. According to [10], a corporate sustainability report development brings some reflections regarding the business practices, and is aligned to good corporate governance practices. The need to consider strategically sustainability comes to meet the growing society demand for more accountability and transparency from companies. In this context, there are tools for financial and non-financial demonstrations, such as the Global Reporting Initiative (GRI) directives, the Dow Jones Sustainability Index (DJSI), the BM&FBovespa Corporate Sustainability Index (ISE), the Global Compact (GC), the Ethos Indicators, and the ISO standards. There are also some sectorial initiatives, such as the Forest Stewardship Council (FSC), the Sustainable Apparel Coalition (SAC), and Biocalce, and some companies’ initiatives, such as the Nike Materials Sustainability Index, and the Timberland Responsibility. The usage of these tools helps companies to identify in which areas they should work to become more sustainable.

A. Existing systems of indicators

The guidelines published by the GRI are a globally recognized reporting guide applied on the economic, environmental, and social aspects of an organization [14]. The guide can be used by organizations of any type of industry or size and has two parts: the first deals with aspects of defining content, quality and limitations of the report, while the second deals with the company profile, management approach and indicators. The organization may file the report and certify it through external evaluation. Depending on which indicators the company met, it can get as a result one of the GRI levels, C, B or A, the latter being the most complete. If a certifier rates the report, the company can get the levels C+, B+ or A+ [15].

The DJSI tracks the performance of the leading companies in the world in economic terms (also including some governance indicators), social and environmental issues. It can be used as a benchmark for investors who consider sustainability aspects in their portfolios [16]. In the economic dimension, the indicators comprise corporate governance practices, investor relationship, customer relationship, code of conduct, risk management and other industry-specific criteria. In the social dimension, labor practices, human capital development, attraction and retention of talent, knowledge management, citizenship and philanthropy and other industry-specific criteria. In the environmental dimension, in addition to industry-specific criteria, are evaluated the company’s environmental policy, environmental performance, environmental reports and the environmental management system. Through the analysis of a list of the largest global companies, the companies with the best performance in each of the economy sectors are selected according to the answers given to the questionnaires [17].

ISE is an instrument of the Brazilian Stock Exchange (BM&FBovespa), which aims to list the company’s stock (up to 40 companies) having the best sustainability practices. Companies with 200 most liquid stocks on the stock exchange are invited to participate. Companies then volunteer to complete a questionnaire assessment, which considers seven dimensions: general nature of the product, corporate governance, financial-economic, environmental, social, and climate change. The reports are released only upon authorization of the companies that filled them. The companies that agreed to compose the index will stay one year in the portfolio [15].

The GC is a voluntary initiative for corporations to commit to human and labor rights, environment and anti-corruption practices through ten principles. The only requirement to join is to sign a statement of commitment to these principles. The instrument has been target of criticism for not having constant monitoring of the signatories. Even that, it is a good driver for companies seeking more sustainable practices [18].

The Ethos Indicators, a Brazilian initiative, is a reference set for social responsibility practices in companies of any size or sector. Through a self-assessment questionnaire with 40 indicators divided into seven sections - values; transparency and governance; internal public; environment; suppliers; consumers and customers; community; government and society, the interested company electronically forwards the responses to the Ethos Institute and receives a report comparing it with the average of the ten companies with the best grades. The company can then check in which areas should act to be more socially responsible [15] [19].

Two ISO standards families are associated to the sustainability theme: ISO 14000 relates to environmental management, and ISO 26000 relates to social responsibility. ISO 14000 includes a series of environmental management standards, being the 14001 standard the most used - and the only certifiable. Currently, there are over 250,000 certificates worldwide in companies of different sizes and sectors. The
following steps are provided in the standard: develop an environmental policy; identify the company's activities, products and services that have interaction with the environment; identify legal and regulatory requirements; identify business priorities and set objectives and targets to reduce the environmental impact and adjust the organizational structure of the company to achieve these goals; check and correct the environmental management system [15] [20].

ISO 26000 deals with guidelines on Corporate Social Responsibility for any interested company. Although not certifiable, it is a reference tool covers social responsibility concepts, terms and definitions. It deals with historical data, trends and characteristics of social responsibility; principles and practices relating to social responsibility; core subjects and issues pertaining to social responsibility; integration, implementation, and promotion of socially responsible behavior throughout the organization and through its policies and practices; identification and engagement of stakeholders, communication commitments, performance and other social responsibility information [21].

The FSC certification focus on responsible management of forest resources. It is a voluntary instrument designed specifically for certification of forest products. Considering ten principles and criteria, which describe how forests should be managed to meet the social, economic, environmental and cultural products, the certified products can be 100% certified or have recycled or mixed sources, and must meet certain percentage of certified origin, attested by a certifier [15].

SAC focus on creating and implementing an index to measure environmental and social performance of apparel and footwear industries. Evaluating materials, products, facilities, and processes, the tool allows, through self-assessment, that small and large companies understand which aspects they need to improve to be more sustainable in the production chain [22].

Biocalce is a certificate for shoes, aiming to ensure comfort, quality, strength and durability in materials free of toxic substances. The certificate is issued after a series of laboratory tests. As additional features, the shoes can also be biodegradable, chrome-free, made from natural substances, PVC-free, anti-slip, use recycled material, among others [23].

As companies’ initiatives, we can cite the Nike and Timberland cases. The Nike Materials Sustainability Index (MSI) is a suppliers’ evaluation tool that focus on less impacting materials usage, including shoes and apparel [24]. The Timberland Responsibility program deals with supply chain management environmental and social issues [25].

B. Development of a specific system of indicators

The existence of this myriad of systems poses a challenge to companies aiming at being more sustainable. This is even more challenging for smaller companies. Further investments in processes and mechanisms to address these systems are generally costly, but necessary, by enabling the increase of competitiveness and opening new markets. Figge et al. [13] listed the following requirements for a system of sustainability indicators: (i) the process must integrate environmental and social perspectives to the business management; (ii) a system of indicators that meets the specific characteristics of a business unit should not be generic, should be specific to that business; (iii) the environmental and social aspects of a business unit must be integrated according to their strategic importance. Considering these challenges and requirements, and the footwear sector characteristics, we proposed a new system of indicators, the Sustainability Seal.

III. METHODOLOGY FOR THE SUSTAINABILITY SEAL DEVELOPMENT

The methodology used for the development of the Sustainability Seal had four main steps:

1. Preparatory phase. This phase comprises an initial bibliographic review and the development of a current situation questionnaire to be applied in some industries of the footwear sector. This survey was applied and the data collected analyzed to identify which indicator sub-categories the Seal must comprise. The famous pillars from the triple bottom line were used (economic, environmental, and social pillars), including a forth pillar, the cultural as a competitive advantage of the Brazilian companies.

2. Review of other systems of indicators. A mapping of the other existing initiatives was developed considering the aforementioned systems: GRI, DJSI, ISE, Global Compact, Ethos Indicators, ISO Standards, FSC, SAC, Biocalce, and some companies’ initiatives. The objective was to identify which indicators must be included in the Sustainability Seal to align it to international initiatives and practices.

3. Discussions with experts and the sector association. The literature references were discussed and the main premises of the Seal were established: be inclusive, that is, consider the current situation of the different footwear industries sub-sectors and make it feasible for them to participate in the initiative aiming to be more sustainable; and be aligned with the international initiatives.

4. Indicators specification. Considering the industries current situation identified by the first questionnaire, the literature review and the discussions with experts, we proposed a set of 52 indicators. We developed a new questionnaire to define the importance level of each indicator in the footwear sector. The analysis of this questionnaire supported the definition of different maturity levels (White, Bronze, Silver, Gold, and Diamond), and the distribution of the indicators in three categories (obligatory, very important, and desirable), according to the local laws and implementation issues.

The next section presents the Footwear Sustainability Seal.

IV. THE FOOTWEAR SUSTAINABILITY SEAL

The proposed Sustainability Seal has 52 indicators organized according to four pillars: economic (“IE”), environmental (“IA”), social (“IS”) and cultural (“IC”), the latter being one of the main innovations of the Seal. The indicators within these pillars are classified into three categories: obligatory (“O”), very important (“V”) and desirable (“D”). Table I lists the indicators, divided by category.
### TABLE I. SUSTAINABILITY SEAL INDICATORS

<table>
<thead>
<tr>
<th>Category</th>
<th>Economic Indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>O</td>
<td>IE1 - Rational Use of Water</td>
</tr>
<tr>
<td>O</td>
<td>IE2 - Rational Use of Electrical Energy</td>
</tr>
<tr>
<td>O</td>
<td>IE3 - Use of Renewable and Non-Renewable Energy</td>
</tr>
<tr>
<td>O</td>
<td>IE4 - Rational Use of Raw Materials</td>
</tr>
<tr>
<td>O</td>
<td>IE5 - Performance Evaluation of Production Employees</td>
</tr>
<tr>
<td>O</td>
<td>IE6 - Machines Productivity Control</td>
</tr>
<tr>
<td>O</td>
<td>IE7 - Participation in Quality &amp; Productivity Programs</td>
</tr>
<tr>
<td>O</td>
<td>IE8 - Investment in Research &amp; Development</td>
</tr>
<tr>
<td>V</td>
<td>IE9 - Treatment and Reuse of Water</td>
</tr>
<tr>
<td>V</td>
<td>IE10 - Rational Use of Fuels</td>
</tr>
<tr>
<td>VI</td>
<td>IE11 - Sustainable Destination of Raw Material Manufactured in Excess</td>
</tr>
<tr>
<td>VI</td>
<td>IE12 - Rejected Products - Recovered, Returned as Raw Material or Recycled</td>
</tr>
<tr>
<td>VI</td>
<td>IE13 - Quality Management Systems certification - ISO 9001</td>
</tr>
<tr>
<td>VI</td>
<td>IE14 - Strategic Planning focusing on Sustainability</td>
</tr>
<tr>
<td>D</td>
<td>IE15 - Use of Alternative Sources of Renewable Energy</td>
</tr>
<tr>
<td>D</td>
<td>IE16 - Objectives and Results Disclosure</td>
</tr>
<tr>
<td>D</td>
<td>IE17 - Local Community Employees Recruitment</td>
</tr>
</tbody>
</table>

#### Environmental Indicators

| O        | IA1 - Raw Material Origin Control                                                  |
| O        | IA2 - Selective Collection                                                          |
| O        | IA3 - Wastewater, Emissions, and Solid Waste Treatment, Reusing & Recycling         |
| O        | IA4 - Use of Recyclable Packaging                                                   |
| O        | IA5 - Packaging Use Optimization                                                   |
| O        | IA6 - Collective Transport Support                                                  |
| V        | IA7 - Development of Sustainable Products & Services                                |
| V        | IA8 - Product Development focusing on Reducing Generation of Wastewater, Emissions, and Solid Waste |
| V        | IA9 - Product Development without Toxicity                                          |
| V        | IA10 - Chemicals Consumption Control                                                |
| V        | IA11 - Chemicals Waste Treatment                                                    |
| V        | IA12 - Waste Treatment Solution for Customers                                       |
| VI       | IA13 - Alignment with the Brazilian National Policy on Solid Waste                  |
| D        | IA14 - Use of Recyclable Raw Materials                                              |
| D        | IA15 - Use of Raw Material of Renewable Source                                      |
| D        | IA16 - Compliance with Environmental Management System certification - ISO 14001    |
| D        | IA17 - Replacement of chemical solvent by water-based solvent or removal of solvent |

#### Social Indicators

| O        | IS1 - Safety and Preventive Health Practices                                        |
| O        | IS2 - Clean and Safe Environment                                                    |
| O        | IS3 - Company Environment Encourages Productivity                                   |
| O        | IS4 - Compliance with Labor Laws                                                    |
| VI       | IS5 - Conducting Socio-environmental Programs and Campaigns among Employees, Customers and Suppliers |
| VI       | IS6 - People and Leadership Training                                                 |
| VI       | IS7 - Additional Benefits to those established by Law                                |
| D        | IS8 - Social and Environmental Projects Support                                     |
| D        | IS9 - Sustainability Products and Services                                          |
| D        | IS10 - Employees Education Incentive                                                |
| D        | IS11 - Conducting of Company-Community Integration Programs                          |

### Cultural Indicators

| O        | RC1 - Protection of the Company’s History, Culture and Values                       |
| O        | RC2 - Employee’s Engagement in Preservation of Corporate Culture Programs            |
| O        | RC3 - Promotion of Sustainability Actions focusing on Culture for Stakeholders / Employees |
| VI       | RC4 - Disclosure and Dissemination of Social Balance                                |
| D        | RC5 - Support for a Business Model focused on Sustainability and Valorization of Culture |
| D        | RC6 - Sustainability Principles Awareness and Culture Valorization                   |
| D        | RC7 - Protection of History, Culture and Values of the Local, Regional and National Community |
Actors:
Adm: Administrator (Seal Manager)
User: Company
Cert: Certifier

*The Diamond Seal requires first the Gold Seal

Figure 1. Sustainability Seal Workflow.

Figure 2. Case Studies Answers for Each Indicator.
Only in the cultural pillar, the less attended indicator is a very important one, IC4 (Disclosure and Dissemination of Social Balance), not a desirable. We believe this is an indication of an adjustment to be made on the Seal: whether reassessing the classification of the indicator, or improving the question, to be broader or to include other types of communications initiatives and reporting. The use of the Seal itself can help companies in this issue. Besides, one of the economic indicators demands a deeper analysis: IE3 (Use of Renewable and Non-Renewable Energy). The indicator had many "No" answers, even with the Brazilian energy matrix being mostly hydroelectric. Two indicators have also raised doubts: IE6 (Machines Productivity Control) and IA10 (Chemicals Consumption Control). In the case of IE6, labor-intensive companies should have the option to answer "Not Applicable", and, in the case of IA10, the same applies to chemical companies. This resulted in the adjustment of the Seal to allow “Not Applicable” answers to some indicators.

VI. CONCLUSIONS

Sustainability is a new form of innovation and competitive advantage, which can lead to lower costs, risk reduction and increased revenues [26]. Creating a specific Seal for the footwear sector aims to bring these opportunities to a sector that has lost market share in recent years. The Seal is innovative because (i) it is specific to the footwear industry; (ii) it does not focus only in environmental and social pillars, a common practice among the other tools, making it difficult to incorporate sustainability practices into the companies’ strategic planning, and (iii) it incorporates culture as a pillar, besides being inclusive and planning a step-by-step adoption.

The Seal development was conducted through an extensive literature review and through questionnaires to develop and validate the system of indicators. The main contributions of this work were the development of a system of indicators that fully meet the needs of the footwear industry in Brazil, besides presenting a method that can be used to develop similar systems for other sectors. The Seal is part of a main program, the “Sustainable Origin”, a broader effort to promote sustainability and increase the footwear sector’s competitiveness. As future works, we envision conducting case studies in the associated companies to verify the current situation and deepen the understanding of the impact of this Sustainability Seal in the sector. By the time this paper was concluded, besides the first 11 companies assessed, other 20 were starting the evaluation process.

VII. REFERENCES

Study of Environmental Sustainability of Three Municipalities Using Emergy Synthesis

C. M. V. B. Almeida, F. Sevegnani, F. Agostinho and B. F. Giannetti
Paulista University
Post Graduation Program in Production Engineering
São Paulo, Brazil
cmvbag@unip.br

Abstract— The great urban population growth generates several changes in life style, land use, energy demand and consequent environmental pressure. In this way, studies related to environmental sustainability of urban systems and the availability of natural resources are of major importance. EMergy is considered to be a powerful tool to environmental accounting and measures both natural and human resources to generate products and services. The evaluation through eMergy synthesis of cities, states, nations and its base resources provides large scale perspective to evaluation of environmental areas and can help selection of policies for public benefit. This preliminary study applies the eMergy synthesis to evaluate the sustainability of the cities that compose the ABC Paulista, accounting the local free renewable and the purchased resources that give support to the cities.

Keywords— Emergy synthesis, environmental accounting, environmental sustainability, urban systems

I. INTRODUCTION

Cities can be regarded as centers of several activities, being them commercial, industrial, social, economic or politics. Such activities have an effect on the biosphere as major consumers of resources and environmental services that often are not within cities' boundaries. Cities need areas, people, materials, knowledge and other resources for the various activities they held, depending on a greater or lesser degree on activities undertaken in other regions, often quite distant. Among these activities one can consider the growth of food, fuel production, water treatment, storage systems for solid waste, people training, production of raw materials and other miscellaneous activities that can’t be developed within the limits of the municipality. The existence and maintenance of a city and its internal structure depends on the flow of products and services into, through and out of town [1]. Thus, for cities maintenance and existence, there must be a constant flow of energy in the form of materials, people, knowledge and other crossing the boundaries of the municipality that comes from various locations in the biosphere.

Through the concept of eMergy accounting it is possible to account the exchanges between the municipality and the "external environment" in order to assess its sustainability. It is possible to evaluate the real wealth of a region with a more realistic vision than the vision purposed by the economic evaluation of gross domestic product (GDP) or social assessment performed by the human development index (HDI). The approaches of GDP and HDI differ drastically from the strong definition of sustainability [2].

EMergy evaluation of states, nations and their resource basis gives large-scale perspective to appraisal of environmental areas, and helps to select policies for public benefit [3]. Considering that cities are a special type of ecosystem, Odum et al. [4] suggested the need for a more comprehensive view of the resources and environmental services provided by the biosphere.

The use of eMergy accounting has already been explored by many researchers in various applications, including the study of urban systems. The sustainability of Rome was studied by Ascione et al. [5] and compared with the sustainability values of Italy. Zhang et al. [6] studied the metabolism of Beijing based in the eMergy synthesis. Law et al. [7] evaluated the dynamic urban system and the economic development of Macao. Huang [8] has developed standards of urban sustainability indicators for Taiwan. A standard for integrated regional studies through a spatial analysis based on eMergy in the province of Cagliari in Italy was developed by Pulselli et al. [9].

ABC Paulista is composed of three municipalities: Santo André, São Bernardo do Campo and São Caetano do Sul. ABC is an important industrial, technological and housing area that gives support to Great São Paulo, deserving a more comprehensive study regarding its environmental sustainability. This paper presents a study of sustainability of the ABC Paulista using the eMergy accounting to assess the inputs of local renewable resources and purchased resources necessary for the maintenance of urban activities.

II. METHOD

Odum [3] emphasizes that eMergy accounting is a science-based evaluation system that is able to represent both environmental and economic values in a common metric. EMergy, spelled with an “m”, is the memory energy or the total of energy embodied into a product or service. It is defined as the sum of all direct or indirect energy to generate a product or service [3].
The contributions of energy to generate a product or service are expressed in a common base (solar equivalent joules, seJ) allowing its accounting.

Transformity measures the relationship between eMergy and energy, and is the eMergy needed to obtain 1 J of a product or service directly or indirectly [10]. Its unit is seJ/J. In some one can calculate as the eMergy needed to obtain one unit of product or service. Then, the eMergy needed to produce one kilogram of any material (seJ/kg) is defined as the specific eMergy.

The eMergy accounting starts with the construction of an energy flow diagram (Fig. 1) identifying resources flows crossing the system boundary. The construction of the diagram is performed with the use of specific symbols (Table 1) that standardize its construction. In the diagram, flows are identified as renewable (R), nonrenewable (N) and purchased resources (F). Resources R and N are provided by the environment and are “economically free”. However, resources can only be considered renewable if they are being consumed at a slower rate than that of its replacement. Water, for example, depending on the local conditions, cannot be considered as renewable if the speed which it is being consumed exceeds the speed of its replacement. Similarly, N resources are those consumed faster than the replacement speed. The F resources are economically acquired and may be accounted in monetary or physical units, which can be transformed into equivalent eMergy (seJ) [3].

The next step in eMergy accounting is mounting of eMergy flows tables that enable analysis, interpretations and eMergy indices calculation. The assembly of the tables is based on the features shown in the diagram.

III. RESULTS AND DISCUSSION

The energy flow diagram shows the renewable natural resources (rain, wind and sun) that feed ABC Paulista. The Billings dam is located at São Bernardo do Campo giving supplying water to various municipalities in the region of Great São Paulo. This storage was considered a non-renewable resource (N). The municipalities purchase resources from outside their borders, and these resources (F) are shown in the upper part of the diagram (water, fuel, electricity, machinery, products and services).

On the right in the diagram are illustrated the financial transactions between municipalities and counties to foreign markets. In addition, the ABC receives an influx of workers and immigrants. Within the limits of ABC’s diagram, the infrastructure of urban activities represented by built and natural systems is shown.

There are also activities that are undertaken within ABC area in order to supply the needs of the municipality regarding water treatment and waste disposal. Industrial and manufacturing activities use the built environment and almost all items that cross the system’s boundary yielding products and services that are exported to other locations outside the system. All these activities generate a stock of capital that is represented within the studied system.

### TABLE I. MAIN SYMBOLS FOR ENERGY DIAGRAM CONSTRUCTION

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arrow</td>
<td>A pathway proportional to the quantity in the storage or source upstream.</td>
</tr>
<tr>
<td>Source</td>
<td>Outside source of energy delivering forces according a program controlled from outside; a forcing function.</td>
</tr>
<tr>
<td>Heat sink</td>
<td>Dispersion of potential energy into heat that accompanies all the real transformation processes and storages; loss of potential energy from further use by the system.</td>
</tr>
<tr>
<td>Tank</td>
<td>A compartment of energy storage within the system storing a quantity as the balance of inflows and outflows; a state variable.</td>
</tr>
<tr>
<td>Box</td>
<td>Miscellaneous symbol to use for whatever unit or function is labeled.</td>
</tr>
<tr>
<td>Interaction</td>
<td>Interactive interaction of two pathways coupled to produce an outflow in proportion to a function of both; control action of one flow on another; limiting factor action; work gate.</td>
</tr>
</tbody>
</table>

Tables 2, 3 and 4 show the emergy flows for each of the municipalities of ABC Paulista and Table 5 presents the eMergy accounting for ABC as a whole.

Calculations of the gross energy of each of the renewable and purchased flows for the municipality of Santo André (SA) are shown below Table 2 in order to illustrate the eMergy table construction. Calculations for the São Bernardo do Campo (SBC) and São Caetano do Sul (SCS) are quite similar, changing only the specific data to each municipality.

Flows identified with (*) come from the same source, and were not accounted to avoid double-counting [3].
### TABLE II. ENVIRONMENTAL EMERGY ACCOUNTING OF SANTO ANDRÉ

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>Unit</th>
<th>Gross Value</th>
<th>UEV(sej/unit)</th>
<th>EMergy (sej/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1(*)</td>
<td>Solar Energy</td>
<td>J/yr</td>
<td>7.55x10^13</td>
<td>[1]</td>
<td>7.55x10^13</td>
</tr>
<tr>
<td>2(*)</td>
<td>Rain Chemical Energy</td>
<td>J/yr</td>
<td>6.86x10^13</td>
<td>[3]</td>
<td>6.86x10^13</td>
</tr>
<tr>
<td>4(*)</td>
<td>Kinetic Wind Energy</td>
<td>J/yr</td>
<td>3.33x10^14</td>
<td>[3]</td>
<td>8.17x10^14</td>
</tr>
<tr>
<td>5</td>
<td>Geothermal Heat</td>
<td>J/yr</td>
<td>2.98x10^14</td>
<td>[3]</td>
<td>1.73x10^14</td>
</tr>
<tr>
<td>Total of renewable resources (R) &amp; Purchased (F)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.39x10^15</td>
</tr>
</tbody>
</table>

### TABLE III. ENVIRONMENTAL EMERGY ACCOUNTING OF SBC

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>Unit</th>
<th>Gross Value</th>
<th>UEV(sej/unit)</th>
<th>EMergy (sej/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1(*)</td>
<td>Solar Energy</td>
<td>J/yr</td>
<td>1.75x10^13</td>
<td>[1]</td>
<td>1.75x10^13</td>
</tr>
<tr>
<td>2(*)</td>
<td>Rain Chemical Energy</td>
<td>J/yr</td>
<td>3.06x10^13</td>
<td>[3]</td>
<td>2.48x10^14</td>
</tr>
<tr>
<td>3</td>
<td>Rain Geopoten. Energy</td>
<td>J/yr</td>
<td>1.45x10^14</td>
<td>[3]</td>
<td>2.77x10^14</td>
</tr>
<tr>
<td>4(*)</td>
<td>Kinetic Wind Energy</td>
<td>J/yr</td>
<td>2.75x10^14</td>
<td>[3]</td>
<td>1.89x10^14</td>
</tr>
<tr>
<td>5</td>
<td>Geothermal Heat</td>
<td>J/yr</td>
<td>8.91x10^14</td>
<td>[3]</td>
<td>4.01x10^14</td>
</tr>
<tr>
<td>Total of renewable resources (R) &amp; Purchased (F)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.85x10^16</td>
</tr>
</tbody>
</table>

### TABLE IV. ENVIRONMENTAL EMERGY ACCOUNTING OF SCs

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>Unit</th>
<th>Gross Value</th>
<th>UEV(sej/unit)</th>
<th>EMergy (sej/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1(*)</td>
<td>Solar Energy</td>
<td>J/yr</td>
<td>6.47x10^16</td>
<td>[1]</td>
<td>6.47x10^16</td>
</tr>
<tr>
<td>2(*)</td>
<td>Rain Chemical Energy</td>
<td>J/yr</td>
<td>2.98x10^18</td>
<td>[3]</td>
<td>2.98x10^18</td>
</tr>
<tr>
<td>4(*)</td>
<td>Kinetic Wind Energy</td>
<td>J/yr</td>
<td>7.90x10^16</td>
<td>[3]</td>
<td>7.90x10^16</td>
</tr>
<tr>
<td>5</td>
<td>Geothermal Heat</td>
<td>J/yr</td>
<td>1.48x10^18</td>
<td>[3]</td>
<td>1.48x10^18</td>
</tr>
<tr>
<td>Total of renewable resources (R) &amp; Purchased (F)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.01x10^19</td>
</tr>
</tbody>
</table>

### TABLE V. ENVIRONMENTAL EMERGY ACCOUNTING OF ABC PAULISTA

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>Unit</th>
<th>Gross Value</th>
<th>UEV(sej/unit)</th>
<th>EMergy (sej/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1(*)</td>
<td>Solar Energy</td>
<td>J/yr</td>
<td>2.57x10^10</td>
<td>[1]</td>
<td>2.57x10^10</td>
</tr>
<tr>
<td>2(*)</td>
<td>Rain Chemical Energy</td>
<td>J/yr</td>
<td>5.86x10^10</td>
<td>[3]</td>
<td>1.79x10^10</td>
</tr>
<tr>
<td>3</td>
<td>Rain Geopoten. Energy</td>
<td>J/yr</td>
<td>4.70x10^10</td>
<td>[3]</td>
<td>2.75x10^10</td>
</tr>
<tr>
<td>4(*)</td>
<td>Kinetic Wind Energy</td>
<td>J/yr</td>
<td>2.45x10^10</td>
<td>[3]</td>
<td>2.77x10^10</td>
</tr>
<tr>
<td>5</td>
<td>Geothermal Heat</td>
<td>J/yr</td>
<td>5.80x10^9</td>
<td>[3]</td>
<td>5.80x10^9</td>
</tr>
<tr>
<td>Total of renewable resources (R) &amp; Purchased (F)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.34x10^10</td>
</tr>
</tbody>
</table>

Results of Tables 2 to 5 show that ABC Paulista’s total EMergy is composed by the contribution of the three municipalities. São Bernardo do Campo and Santo André contribute with similar shares (44% and 47%, respectively), and São Caetano do Sul, the smallest in area, contributes with the remaining 9%. Among the renewable resources accounted (rain and geothermal heat), rain contributes to the operation of this urban center more than 80% sej/sej, and each municipality receives from 15 to 20% of renewable resources in the form of geothermal heat. Among the purchased resources, fuels and electricity are the most important inputs. Electricity stands for 62% of ABC’s total energy and, among fuels (33% sej/sej), natural gas is the main input, corresponding to 14% of the total energy.

Analyzing the data shown in Table 6, it is clear that the municipalities depend much more on the purchased resources (F) than on its own renewable resources. The percentage of renewables contribution is less than 5% sej/sej for all municipalities. This is a common characteristic of urban centers that concentrate activities that need resources provided by various locations coming from outside their limits [5-9].

Considering the population of each municipality permits to observe that the share corresponding to each inhabitant is not proportional to the share of each municipality as a whole. The population of São Caetano do Sul receives more renewable resources than the inhabitants of Santo André and São Bernardo do Campo, which are more populated. The municipality of São Caetano do Sul is averagely industrialized and possibly the high value of purchased resources compensates the low natural resources inputs. Furthermore, Santo André and São Bernardo do Campo are highly industrialized, and a part of the purchased resources is used directly by the industry and cannot be seen as a wealth factor for their populations.
TABLE VI. PER CAPITA ENERGY OF THE ABC PAULISTA MUNICIPALITIES

<table>
<thead>
<tr>
<th>Municipality</th>
<th>Popul.x 10^3</th>
<th>% R</th>
<th>Per capita Energy (socJ/year inhab)</th>
<th>% R/ person</th>
<th>% F/ person</th>
</tr>
</thead>
<tbody>
<tr>
<td>Santo André</td>
<td>6.73</td>
<td>3</td>
<td>2.07x10^10</td>
<td>6.51x10^10</td>
<td>0.000005</td>
</tr>
<tr>
<td>São Bernardo do Campo</td>
<td>8.11</td>
<td>4</td>
<td>2.28x10^14</td>
<td>4.97x10^13</td>
<td>0.000005</td>
</tr>
<tr>
<td>São Caetano do Sul</td>
<td>1.52</td>
<td>1</td>
<td>6.67x10^13</td>
<td>5.97x10^13</td>
<td>0.000007</td>
</tr>
<tr>
<td>ABC</td>
<td>16.4</td>
<td>3</td>
<td>2.04x10^14</td>
<td>5.70x10^13</td>
<td>0.000002</td>
</tr>
</tbody>
</table>

IV. CONCLUSIONS

This work accounts the renewable resources (R) and the purchased resources (F) for the municipalities that belong to the ABC Paulista. Results make clear that cities that are understood as central bodies of various activities, depend on a support area larger than its own to keep their business. When referring to the use of free resources provided by the biosphere it is possible to arrange the cities in descending order as follows: São Bernardo do Campo, Santo André and São Caetano do Sul. When referring to the availability of renewable resources for the population of each municipality, it was found that the population of São Caetano do Sul can take advantage of additional resources provided by nature. It was also noted that the renewable energy per capita of Santo André is slightly lower than that of São Bernardo do Campo. However, São Caetano do Sul has approximately four times less renewable resources per capita than the other two municipalities that form the ABC Paulista, but its population benefits more of the available resources.

ACKNOWLEDGMENT

Acknowledgements to Universidade Paulista – UNIP specially to the Production and Environment research group that is part of the Master and Doctoring in Production Engineering Program. Special thanks are addressed to CNPq for financial support.

REFERENCES


APPENDIX

Calculations for Table’s items:

Item 1 - Calculation of solar energy according to eq. 1:

\[
\text{Energy (J)} = \text{(municipality area) } \times \text{(avg. solar radiation) } \times \text{(cm²/m²) } \times \text{(1-albedo) } \times \text{(J/kcal)}
\]

\[
\text{Energy (J)} = (1.75 \times 10^8 \text{m}^2) \times (3.1) \times (0.8) \times (1.00 \times 10^4) \times (9.8) \times (4.94 \times 10^3) \times (1-0.22) \times (4186) \times \frac{\text{kcal}}{\text{J}}
\]

Energy (J) = 7.55x10^17 kcal / yr

Item 2 - Calculation of chemical energy of the rain according to eq. 2:

\[
\text{Energy (J)} = \text{(municipality area) } \times \text{(avg. rain fall discounted evap.*) } \times \text{(water density) } \times \text{(Gibbs free energy)}
\]

\[
\text{Energy (J)} = (1.75 \times 10^8 \text{m}^2) \times (0.8 \times 0.001) \times (1000 \text{g/m}^3) \times (4.94 \times 10^3) \times (1.00 \times 10^4) \times (100) \times (1000) \times (80) \times (85) \times (1-0.22) \times (4186) \times \frac{\text{kcal}}{\text{J}}
\]

Energy (J) = 2.60x10^15 kcal / yr

Item 3- Calculation of geopotential energy of the rain according to eq. 3:

\[
\text{Energy (J)} = (1.75 \times 10^8 \text{m}^2) \times (3.1 \text{m/yr}) \times (0.64) \times (760 \text{m}) \times (9.8 \text{m/s}^2) \times (1-0.22) \times (4186) \times \frac{\text{kcal}}{\text{J}}
\]

Energy (J) = 2.60x10^15 kcal / yr

Item 4- Calculation of kinetic wind energy according to eq. 4:

\[
\text{Energy (J)} = \text{(municipality area) } \times \text{(air density) } \times \text{(drag coef. } \times \text{(speed\') } \times \text{(transf. years to seconds)}
\]

\[
\text{Energy (J)} = (1.75 \times 10^8 \text{m}^2) \times (1.22 \text{kg/m}^3) \times (0.64) \times (760 \text{m}) \times (0.001) \times (1000) \times (1-0.22) \times (4186) \times \frac{\text{kcal}}{\text{J}}
\]

Energy (J) = 2.60x10^15 kcal / yr

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Energy (J) = \((1.75 \times 10^8 m^3) \times (1.3 \times 10^{-3}) \times (3.6 \times 10^7 \frac{m}{s}) \times (3.14 \times 10^7 \frac{J}{s})\) Energy (J) = \(3.33 \times 10^{14} \frac{J}{yr}\)

**Item 5-** Calculation of geothermal heat according to eq. 5:

Energy (J) = (municipality area) \(\times\) (deep heat flow)

Energy (J) = \((1.75 \times 10^8 m^3) \times (1.70 \times 10^6 \frac{J}{yr})\) Energy (J) = \(2.98 \times 10^{14} \frac{J}{yr}\)

**Item 6-** Calculation of energy of diverse fuels according to eq. 6:

**Item 6a-** Calculation of energy of natural gas according to eq. 6:

Energy (J) = \((3.10 \times 10^8 \frac{m^3}{yr}) \times (8800 \frac{kcal}{m^3}) \times (4186 \frac{J}{kcal})\) Energy (J) = \(1.14 \times 10^{16} \frac{J}{yr}\)

**Item 6b-** Calculation of energy of gasoline according to eq. 6:

Energy (J) = \((1.41 \times 10^8 \frac{L}{yr}) \times (7844.2 \frac{kcal}{L}) \times (4186 \frac{J}{kcal})\) Energy (J) = \(4.63 \times 10^{15} \frac{J}{yr}\)

**Item 6c-** Calculation of energy of diesel oil according to eq. 6:

Energy (J) = \((2.23 \times 10^8 \frac{L}{yr}) \times (5096.7 \frac{kcal}{L}) \times (4186 \frac{J}{kcal})\) Energy (J) = \(2.23 \times 10^{15} \frac{J}{yr}\)

**Item 6d-** Calculation of energy of sugarcane ethanol according to eq. 6:

Energy (J) = \((1.01 \times 10^8 \frac{L}{yr}) \times (5096.7 \frac{kcal}{L}) \times (4186 \frac{J}{kcal})\) Energy (J) = \(2.15 \times 10^{15} \frac{J}{yr}\)

**Total energy of fuels (J) = 2.04 \times 10^{16} \frac{J}{yr}\)

**Item 7-** Calculation of energy of electricity according to eq. 7:

Energy (J) = \((2.77 \times 10^9 \frac{kWh}{yr}) \times (3.60 \times 10^6 \frac{J}{kWh})\) Energy (J) = \(9.97 \times 10^{15} \frac{J}{yr}\)

**Item 8-** Calculation of energy of treated water according to eq. 8:

Energy (J) = \((avg. \text{ consumption per capita}) \times (transf. liters to m}^3) \times (365 \text{ days per year}) \times (population)\)

Energy (J) = \((2.38 \times 10^8 \frac{L}{day}) \times (1 \times 10^4 \frac{m}{L}) \times (365 \text{ days}) \times (6.73 \times 10^5 \text{ inhabit})\) Energy (J) = \(5.84 \times 10^{17} \frac{J}{yr}\)
Implementation of a Mobile and Stretchable Energy Production System Using P/V Cells

M.G. Papoutsidakis
Dept. of Automation
Technological Institute of Piraeus
Athens, Greece

D. Piromalis
Dept. of Automation
Technological Institute of Piraeus
Athens, Greece

D. Tseles
Dept. of Automation
Technological Institute of Piraeus
Athens, Greece

Abstract—World Energy consumption and the resulting CO₂ emissions are increasing substantially and this increase puts in danger the ecological stability of Earth. Growing scarcity and rising prices of fossil fuels may lead to economical and political instability in many countries in the near future. These problems can be solved by contributing significantly the use of renewable energy resources. The renewable energy resources are sufficient enough to meet the world energy requirement. In this paper, an autonomous energy production system using a single photovoltaic panel is going to be presented. The system is mounted on a trailer with 3 wheels and can be towed by any typical car, even a small one. The parts of the system from energy production to ready for consumption point and their construction will be discussed in details. A significant part of this paper include the description of a future project that will be undertaken in the close future, and will involve four photovoltaic panels in separate frames, in an attempt to increase the power supply and the overall efficiency the system.

Keywords—solar trailer; P/V system; solar tracking; autonomous generator;

I. INTRODUCTION

Nowadays, the renewable energy resources are sufficient enough to meet the world’s energy requirements and provide an alternative option. Most of the countries have started recognizing the new energy policy and need to encourage the investment in renewable resources. Their policies are moving towards an alteration of their energy production profile. Working in the scientific domain of renewable resources, the purpose of this paper is to design and construct a prototype energy production system based on a trailer. The main characteristics of this construction are environment friendly and low cost technology, mobility that ensures easy travelling, high versatility and expandability and meet every day power needs for lightning and low consumption power device operation. The simulation tool we used for our research is the PVGIS Simulation Environment as in earlier work, see [1], [2] and [3], for a 230W system in the area of our Institute, which is located in the surroundings of Athens, Greece. It is an efficient, accurate and user friendly tool for simulating any solar system and a view of its environment can be seen in Fig1. It is a part of the SOLAREC action that contributes to the implementation of renewable energy in the European Union. PVGIS provides many parameters for a solar system. In our research, the main parameters for the simulation are 230Wp for the panel and the choice of the tracking options.

II. SOLAR TRACKER CASE STUDIES

After a considerable large number of testing, the recorded outcome was that if an autonomous system powered by a solar panel 230Wp is positioned firmly in the north hemisphere, it attaches less power in December and January. The two main factors that define the system design are the energy captured from the solar panel during the months of December and January, as well as the amount of energy required for consumption at this period. The horizon settings can be viewed in Fig.2, which are provided by the PVGIS with high accuracy.

Figure 1. PVGIS simulation environment
In our location, Athens, Greece, the short duration of day and the smaller power of the sunlight reduce the energy generated during these months, as the following table of average daily and monthly produced energy indicates:

<table>
<thead>
<tr>
<th>Month</th>
<th>Average Daily Produced Energy (kWh)</th>
<th>Average Monthly Produced Energy (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>0.75</td>
<td>23.2</td>
</tr>
<tr>
<td>Feb</td>
<td>0.84</td>
<td>23.5</td>
</tr>
<tr>
<td>Mar</td>
<td>1.02</td>
<td>31.8</td>
</tr>
<tr>
<td>Apr</td>
<td>1.03</td>
<td>30.8</td>
</tr>
<tr>
<td>May</td>
<td>0.99</td>
<td>30.6</td>
</tr>
<tr>
<td>Jun</td>
<td>1.00</td>
<td>29.9</td>
</tr>
<tr>
<td>Jul</td>
<td>1.01</td>
<td>31.4</td>
</tr>
<tr>
<td>Aug</td>
<td>1.09</td>
<td>33.8</td>
</tr>
<tr>
<td>Sep</td>
<td>1.04</td>
<td>31.2</td>
</tr>
<tr>
<td>Oct</td>
<td>0.99</td>
<td>30.8</td>
</tr>
<tr>
<td>Nov</td>
<td>0.75</td>
<td>22.5</td>
</tr>
<tr>
<td>Dec</td>
<td>0.64</td>
<td>19.9</td>
</tr>
<tr>
<td>Yearly Average Daily Produced Energy</td>
<td>0.930</td>
<td>28.3</td>
</tr>
<tr>
<td>Total Energy for a Year</td>
<td>339</td>
<td></td>
</tr>
</tbody>
</table>

Figure 2. Horizon setting for simulation use

During the same months, December and January, in Athens, Greece, the highest needs in lighting are recorded due to the longer duration of the night (14 hours). The system aims to provide enough electricity mainly for lighting all night. An autonomous system, a fixed or a constant slope, is chosen based on the criterion of best performance in this period as in [4]. In the remaining months, the energy captured per day will be greater and the energy required for lighting will be less. According to the above fact, the selected slope of the photovoltaic panels should be the one that has the highest returns at this period. The slope that gives the maximum energy is the 55° to the south. According to the simulation data coming from the PVGIS environment and the system 230Wp in the Athens area can yield the results presented in Table 1. One can notice, from Table I that the months of December and January gave the lowest average daily energy output 640 and 750Wh, respectively, as expected; yet is gives more energy than that on a slope of about 32° which would have maximum performance throughout the year but at the months of December and January will give lower average energy per day 544Wh and 643Wh respectively. That is why in the rest of our research, we kept the slope of a stable PV panel equal to 55° to the south. Afterwards, in an attempt to increase the performance of the system and enchase its efficiency, a solar tracker was taken under serious consideration. The motivation for that arises from the comparison of using two axis trackers and a fixed system. One can easily observe that two axis trackers have greater performance than a fixed system; and for the system of our research project (230Wp) it gives total energy yield 486 kWh for one year, while a fixed system with a slope at 55° gives only 339 kWh, as the result of Table 1. The difference is smaller in the months that interest us, and the biaxial system only gives 730Wh and 850Wh, respectively, while the fixed 640Wh and 750Wh. At bottom line a system equipped with a solar tracker, offers more power approximately about 15% compared to the fixed system. The following charts in Fig.3 show that during the months of September, October, November, December, January, February and March, the single axis trackers at 55° tilt have an energy efficiency similar to the two axis one. Even if the tilt in single axis Trackers, as the vertical axis and inclined axis is large, around 55°, the system delivers almost the same energy at these months with the two-axis system which has no significant advantage in energy performance.
total annual yield compared to the two-axis. On this basis, the average daily energy systems performance makes feasible the calculation of the daily consumption of the energy generated by the system in December. Ground storage must be taken into account in order to size the system. So a portion of energy should be stored for back up. The underlying logic is that the 40% of the energy produced, is stored in battery charging while the remaining 60% will be consumed for lighting at night. According to this, the system in four to five days will be almost fully charged if a deep discharge comes up. A comparable study of various tracker options is presented in Table III. The column kW is generated by the 60% of the average daily produced energy in December.

Table II demonstrates these results and these data obtained from PVGIS for the above system.

### Table II. ENERGY YIELD FOR VARIOUS TRACKING OPTIONS

<table>
<thead>
<tr>
<th>Month</th>
<th>Average Daily Produced Energy (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fixed System: Inclination=55°, Orientation=0° (South)</td>
</tr>
<tr>
<td>Jan</td>
<td>0.75</td>
</tr>
<tr>
<td>Feb</td>
<td>0.84</td>
</tr>
<tr>
<td>Mar</td>
<td>1.02</td>
</tr>
<tr>
<td>Apr</td>
<td>1.03</td>
</tr>
<tr>
<td>May</td>
<td>0.99</td>
</tr>
<tr>
<td>Jun</td>
<td>1.00</td>
</tr>
<tr>
<td>Jul</td>
<td>1.01</td>
</tr>
<tr>
<td>Aug</td>
<td>1.09</td>
</tr>
<tr>
<td>Sep</td>
<td>1.04</td>
</tr>
<tr>
<td>Oct</td>
<td>0.99</td>
</tr>
<tr>
<td>Nov</td>
<td>0.75</td>
</tr>
<tr>
<td>Dec</td>
<td>0.64</td>
</tr>
<tr>
<td>Yearly Average Daily Produced Energy</td>
<td>0.93</td>
</tr>
<tr>
<td>Total Energy for a Year</td>
<td>339</td>
</tr>
</tbody>
</table>

Observing Fig.3, it can be noticed that the two axis system has a small advantage in summer while in winter months the single axis systems have similar performance to the biaxial; while the vertical axis system has very little difference in the

Regarding Table III, the computation of lighting consumption, for the three scenarios become feasible. The light consumption is computed for the month of December and is
assuming to be the same for the other months. The outcomes are summarized as follows:

a) For a fixed system 384Wh consumption lighting for 14 hours in December. This may contribute to some 28Watt light.

b) For a vertical axis 426Wh consumption lighting for 14 hours in December. This may contribute to 30.5Watt light.

c) For a biaxial and an inclined axis and 432Wh consumption lighting for 14 hours in December. This may contribute to 30.9Watt light.

From the comparative study in Table III, one can observe that for the months December and January, the two-axis, the vertical axis and the inclined axis system have almost equivalent efficiency. Since there is practically no difference in energy production during these months, other criteria defined the tracker choice for our system, such as reliability and mechanical construction issues. The vertical axis tracker combined with a solar panel of 230Wp is the choice that was adopted in the system and will be discussed further in this paper. The lighting consumption that is calculated for December and January is 426Wh. In order to size the battery this consumption should be multiplied by the three days of autonomy (supposed fully cloudy days) in December and the result is 1278Wh and for a 12V battery, one gets 107Ah. This scenario takes into account the energy loss from the charger and the charger cables up having to calculate the loss rate of 14%. The calculation of the battery size should reflect the fact that the battery should not be fully discharged so the value for Ah should be increased so that a 40% of charge remains when the three days of the autonomy are used. This is resulting to: 107Ah \rightarrow 178Ah. The expected lifetime of the battery is calculated by the amount of discharge that the battery will be exposed. Using the considerations in Table III the discharge will reach 17.7% - 11.5% from the December to July.

| Table III. ENERGY YIELD AND CONSUMPTION CORRESPONDENCE |
|---------------------|---------------------|---------------------|---------------------|---------------------|
| Month   | Fixed System: Inclination=55° | Vertical axis: Inclination=55° | Inclined axis: Inclination=55° | 2-axis system |
|         | Average Daily Produced Energy (kWh) | Lighting consumption kWh | Average Daily Produced Energy (kWh) | Lighting consumption kWh | Average Daily Produced Energy (kWh) | Lighting consumption kWh | Average Daily Produced Energy (kWh) | Lighting consumption kWh |
| Jan     | 0.75 | 0.384 | 14 | 0.84 | 0.426 | 14 | 0.85 | 0.432 | 14 | 0.85 | 0.438 | 14 |
| Feb     | 0.84 | 0.357 | 13 | 0.98 | 0.396 | 13 | 0.99 | 0.401 | 13 | 0.99 | 0.407 | 13 |
| Mar     | 1.02 | 0.330 | 12 | 1.31 | 0.365 | 12 | 1.31 | 0.370 | 12 | 1.33 | 0.375 | 12 |
| Apr     | 1.03 | 0.302 | 11 | 1.46 | 0.335 | 11 | 1.42 | 0.339 | 11 | 1.5 | 0.344 | 11 |
| May     | 0.99 | 0.274 | 10 | 1.57 | 0.304 | 10 | 1.49 | 0.309 | 10 | 1.65 | 0.313 | 10 |
| Jun     | 1    | 0.247 | 9  | 1.75 | 0.274 | 9  | 1.62 | 0.278 | 9  | 1.86 | 0.282 | 9  |
| Jul     | 1.01 | 0.247 | 9  | 1.75 | 0.274 | 9  | 1.64 | 0.278 | 9  | 1.85 | 0.282 | 9  |
| Aug     | 1.09 | 0.274 | 10 | 1.66 | 0.304 | 10 | 1.61 | 0.309 | 10 | 1.73 | 0.313 | 10 |
| Sep     | 1.04 | 0.302 | 11 | 1.38 | 0.335 | 11 | 1.37 | 0.339 | 11 | 1.41 | 0.344 | 11 |
| Oct     | 0.99 | 0.329 | 12 | 1.2  | 0.365 | 12 | 1.21 | 0.370 | 12 | 1.21 | 0.375 | 12 |
| Nov     | 0.75 | 0.357 | 13 | 0.85 | 0.396 | 13 | 0.86 | 0.401 | 13 | 0.86 | 0.407 | 13 |
| Dec     | 0.64 | 0.384 | 14 | 0.71 | 0.426 | 14 | 0.72 | 0.432 | 14 | 0.73 | 0.438 | 14 |
| Yearly Average Daily Produced Energy | 0.93 | 1.29 | 1.26 | 1.33 |
| Total Energy for a Year | 339 | 471 | 460 | 486 |
respectively, if we assume no fully cloudy days. This depth of discharge can provide long life for the battery, more than 1700 discharge cycles according to the manufacturer. The used data, from PVGIS are accounting the atmospheric conditions as in [2], and the results provide a mean value for the yield of the year, the month and the day. So if some cloudy days are supposed, this will not affect the yields that is mentioned above in Tables I, II and III. The amount of fully cloudy days can be estimated at 15% for Athens. This is reducing the assuming above discharge cycle by an estimated factor of 30% as in [5], which means that the final estimation for the battery life will be more than 1200 cycles. The temperature influence on the battery can be neglected as the battery will be working at the summer in a very low discharge mode, while at the winter the battery will be working on low temperatures.

III. SOLAR TRACKER DESIGN

The design of the vertical axis tracker can be seen in Fig.4. The innovative point of the design is that the tracker may open and close for the transportation of the trailer. The inclination angle can be manually chosen according to the season, while the vertical axis tracker will function at any chosen angle.

For the construction we use metal profile: 30x30mm and 25x25mm galvanized iron. Fig.4 illustrates the system scaled to those of the real constructed system and one should bear in mind that the bigger dimension of the tracker is 1m. The vertical axis tracker will be placed into the trailer as it can be seen in Fig.5. This type of placement ensures that:

a) During the traveling time of the trailer on the road, no parts or elements disturb, or put in danger the traffic; also this set up, can have the authorization to be a legal trailer, apart from lights, alarms, etc.

b) At the point that the user needs to produce energy, the amount of the wind pressure is faced by the low mass center of the construction.

The user defines the appropriate inclination angle depending on the season. In this way not only in the winter but all the seasons we can capture solar energy with high efficiency. In practice there are only two options for the inclination the winter season at 55° and the summer season at 45°. It is important to mention that at the transmission form the motor to the tracker, worm gears have been used. This type of transmission ensures that the motor consumes energy only for the movement and not constantly (to face the wind load). The movement of the tracker is controlled by two photo-resistances and is proceeding in steps according to the adjustment of the photo-resistances. The circuitry used for the tracker is a low cost though reliable one, based on the fact that a more electronically complex circuit would need more power to operate and the result would not be better. The motor and the driving circuit consume a negligible amount of power due to the tow stages of worm gears of transmission.

An overall view of the mobile solar power generator system can be seen in Fig.6. On the left is the trailer ready for traveling (PV panel placed down) and on the right one can see the automated movement perpendicular to vertical axis for the daily tracking. By this movement, the solar panel enhances the ability to produce energy of almost a factor of 28% of the total energy in a year period compared to the fixed system, as in Table II and III. The components that have been placed on the trailer of 1750x1100x400mm dimensions are a 230Wp PV panel, a 12V/200Ah battery, a 50A battery DC charger, a 2kW inverter for AC power supply, and 30.5W lights.


IV. CONCLUSIONS AND FURTHER IMPROVEMENTS

The designed system uses the scenario of the tilt panel -vertical axis solar tracker. This system is an innovative solution, which has been implemented for usability, simplicity in construction, performance and safety. The motivation of implemented a mobile power generator based on PV cell technology was fulfilled, while at the same time the cost was kept very low but the built quality and the reliability was “vice versa”. The placement of a 230Wp solar panel on a trailer has been discussed, as well as the design procedure. According to global open access data from University of Nebraska and U.S. Naval Observatory Astronomical Applications Department our calculations can be judged rather pessimistic considering that only 20 days (10 to 30 of December) the length of the night is 13.5 hours. This fact makes our system even more efficient in real applications and our predictions in simulation can be considered as safe.

The expansion of the solar trailer can enhance its capability for loads not only for lighting but for multiple everyday uses; the same design can be expanded. A possible setup can be for four panels that reach the order of 1KWp of solar power. In such a system the trailer should have dimensions of 4.2x1.75m. The design of the tracker is the same in practice, although the dimensions should be bigger, in order to support the larger dimensions and the bigger weight as seen in Fig7. An overall investigation in simulation mode will take place at the beginning of this new project, which will ensure again the efficiency of this new implementation.

![Figure 7. The 4 PV panels extended version of the system](image)

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[4] (access date: 27 November 2013)
Valuation of investment projects in the context of sustainable development

Real option approach

Krzysztof S. Targiel
Department of Operations Research
University of Economics in Katowice
Katowice, Poland
krzysztof.targiel@ue.katowice.pl

Abstract—Traditionally, the evaluation of development projects is made on the basis of financial criteria. In the context of sustainable development, the social and environmental aspects must also be considered. Contemporary project valuation takes into account not only the static planned cash flows but also opportunities that may appear, known as real options. This paper describes a method for the valuation of development projects, taking into account the above aspects of valuation.

Keywords- sustainable development; project valuation; real options

I. INTRODUCTION

Traditional project evaluation is based on the discounted cash flow method (DCF). The main measure of effectiveness is the Net Present Value (NPV). When this value is positive, the project is approved, when negative, it is rejected, but this approach sometimes leads to the abandonment of profitable projects. The reason for this is that the DCF method does not take into account the role of managerial flexibility. The Project Manager has the right to take action as appropriate. This situation is called a real option. Using Real Option Valuation (ROV), we can provide a quantitative measurement for this situation.

In ROV, methods from the financial market, such as the Black-Scholes model [2] or the Cox-Ross-Rubinstein model (CRR)[7] were used first. An approach based on Monte Carlo simulations [3] has also been used. The CRR model is based on the binomial tree. This approach was also adopted in Guthrie’s work [9], on which this study is based.

The traditional approach in the valuation of real options is based on one factor called the state variable. There have been attempts to take into account many state variables. The first attempt, on the basis of financial options, was made by Boyle [4], who took into account two assets. Mun [12] described the commercial solution as having such possibilities. Guthrie [9] also described problems for which it was necessary to take into consideration a number of variables.

In these solutions, different criteria were brought to a common financial denominator. The proposed solution considers various aspects such as multi-criteria, which is especially important in the context of sustainable development.

II. PROBLEM FORMULATION

Project management produces an environment in which many decisions are made. Many project management methodologies, such as PRINCE2 [14], for example, recommend dividing the project into stages. This raises the problem of decision making, the choice of the start of the next steps.

According to the PRINCE2 methodology, each project must have at least two stages of initialization and proper implementation. We will consider a project consisting of these two phases, each of which occupies a period of time. After initializing the project we have to decide when to begin implementation. We can delay the execution of one period. This is a classic example of the defer options considered by Ingersoll and Ross [10].

If steps are planned in advance, the situation is static; the decision maker is not able to react to changes in the environment and in the same project. If extending the duration of the project is allowed and the decision maker is allowed to freely decide about the start times of stages, a completely new situation is raised, as presented in Fig. 1. The decision maker may start the project (decision A), then move from the current state (initialization of project) to the last state (end of project). The decision maker may wait (decision W), but then the project will remain in its starting state.

Figure 1. Decision tree
The results of the project, in terms of its value, depend on certain factors, which may be:

- Economic factors (commodity prices, exchange rates)
- Social factors
- Environmental factors

according to the principles of sustainable development. If we consider more than one factor that leads to usability and design considerations in many areas, the problem is converted from a simple valuation to a multi-criteria evaluation problem.

This approach is discussed in the literature. Bednyagin and Gnansounou [1] consider the spillover benefits of the R & D program on thermonuclear fusion technology. The socio-economic benefits are higher than the expected costs. The framework for project-level decisions, leading to more sustainable management and development, is proposed in [6].

The ecological, economic and social sources of landscape valuation are discussed in [15]. Heidkamp's paper [20] proposes a theoretical framework for the integration of economic aspects and environmental aspects into the decision making process for sustainable development strategies. The paper [21] incorporates sustainable development criteria into decision making processes within the industry. Renewable energy investment projects as an integral part of sustainable economic development are discussed in [5] with evaluating real options embedded in these projects.

The decision maker makes its decisions based on the changes in factors. These factors vary stochastically according to a certain random process. The idea behind the CRR method is to cover a possible future state variable binomial tree as shown in Fig. 2. This is a role-specific scenario of possible changes in the value of state variables. At each stage, we consider only the possibility of an increase or decrease in value. With this procedure the decision making process is simplified.

This issue is discussed in the literature by Guthrie [9]. Guthrie considered one such factor, and this article extends these considerations and binds the results of the project with two factors.

---

### III. METHOD OF EVALUATION

We assume that each state variable in one period may increase \( u \)-times and fall \( d \)-times. This assumption leads to the tree of possible state variable values, consisting of nodes marked with indices \((i, n)\) where \(i\) means number of falls and \(n\) means period number.

A state variable and cash flow is connected to each node. We denote it as (in each node \((i,n)\) ):

- \( X_k(i, n) \) – \( k\)-th state variable in period \( n \)
- \( Y_m(i, j, n) \) - cash flow in period \( n \) (where \( m \) is state of project)

We assume that we have \( N \) periods, the present value of each state variable denoted by \( X_k(0,0) \) and also \( u \) and \( d \). The value of \( u \) can be obtained from historical data by the calibration procedure [9].

The proposed procedure consists of the following steps:

A. **Build a decision tree (D-Tree)**

In this step, the possible states of the project are recognized. They may be different phases or specific stages. The possible decisions that could be made when considering a state are recognized. Making a decision would lead to a transition from one state to another. All possible transitions are identified. The result of this step is the creation of a D-Tree. The considered D-Tree is shown in Fig. 1.

B. **Build a lattice of state variables (X-Tree)**

In this step, quantifiable economic magnitudes which may depend on the result of the project (state variables) need to be identified. This currently proposed method does not include the correlation between these variables, assuming it does not exist.

The tree starts from a known present value of state variables. Based on the history of changes of this magnitude, the values \( u \) and \( d \) can be determined in the calibration process. A tree of possible changes in state variables is formed and shows possible scenarios of the situation, presented in Fig. 3. Calibration is an appropriate choice for the number of steps and the choice of parameters \( d, u \), so as to best meet the future value of the variable state.

---

**Figure 2.** The binomial tree covering the stochastic process

**Figure 3.** The binomial tree of state variables
C. Build a tree of the project values (V-Tree)

If a project evaluation is based on many state variables, it is therefore presented in a vector of values. When considering two state variables, the V-Tree grows in two dimensions:

\[
V_m(i', i^2, n) = \begin{bmatrix}
  f_1(X_1(i', i^2, n), V_1(i', i^2, n + 1)) \\
  f_2(X_2(i', i^2, n), V_2(i', i^2, n + 1)) \\
  \vdots \\
  f_s(X_s(i', i^2, n), V_s(i', i^2, n + 1))
\end{bmatrix}
\]

We denote the present value of the project, which is dependent on two state variables, as:

\[
V_{(s)}(i, j, n) - \text{utility value of project in period } n, \text{ with } i - \text{number of falls of first state variable and } j - \text{number of falls of second state variable}
\]

The calculation of the value of the V-Tree starts from the end (final value). We assume that the final value of the project is a function of state variables:

\[
V_{(m)}(i^2, j^2, n) = \begin{bmatrix}
  V_1(i^2, j^2, n + 1) \\
  V_2(i^2, j^2, n + 1)
\end{bmatrix}
\]

On this basis, the remaining values of the V-Tree are successively calculated. Trees are constructed for each state of the project. The calculation of value is done by backward induction. Based on the value of the project after its completion (which is usually equal to the state variable, or the right formula for this variable is calculated), the values of the project in the preceding nodes are calculated.

We will consider two possibilities:

- in the case of financial factors, when the present value is the discounted expected value of subsequent values

\[
V_1(i, j, n) = (\pi_1 V_1(i, j, n + 1) + \pi_2 V_2(i, j, n + 1)) e^{-r\Delta t}
\]

\[
V_2(i, j, n) = (\pi_3 V_1(i, j, n + 1) + \pi_4 V_2(i, j, n + 1)) e^{-r\Delta t}
\]

- in the case of other factors, when the present value is the expected value of subsequent values

\[
V_1(i, j, n) = \pi_1 V_1(i, j, n + 1) + \pi_2 V_2(i, j, n + 1)
\]

\[
V_2(i, j, n) = \pi_3 V_1(i, j, n + 1) + \pi_4 V_2(i, j, n + 1)
\]

Previous values are weighted by the probability of achieving those values, which are also derived from the data.

D. Determine effective transitions (decisions)

The values determined by the formulas (3) – (6) must be calculated for each decision, so we have a superscript denoting the decision on the value achieved:

\[
V^A_{(i, j, n)} = \begin{bmatrix}
  V^A_1(i, j, n) \\
  V^A_2(i, j, n)
\end{bmatrix}
\]

for decision Act and

\[
V^W_{(i, j, n)} = \begin{bmatrix}
  V^W_1(i, j, n) \\
  V^W_2(i, j, n)
\end{bmatrix}
\]

for decision Wait.

Assuming that the project is properly managed, a favorable decision will be chosen.

\[
\text{IF } V^W_{(i, j, n)} > V^A_{(i, j, n)} \text{ THEN Wait; } V_m = V^W_m \\
\text{ELSE Act; } V_m = V^A_m
\]

In (11) the preference between the two vectors must be checked. There are many methods for determining the preferred decision based on the preferences of the decision maker. The simplest solution is used in a dynamic programming scalarization approach [19]. The resulting vector components are weighted coefficients indicating preferences. Single numbers are thus obtained, which can be directly compared.

If we denote:

\[
Q^W_{(i, j, n)} = \sum_k w_k V^W_k(i, j, n)
\]

\[
Q^A_{(i, j, n)} = \sum_k w_k V^A_k(i, j, n)
\]

where \(w_k \geq 0\) are weights of assessments,
the calculations are simplified to:

\[
\text{IF } Q_{\text{in}}^{W(i,j,n)} > Q_{\text{in}}^{R(i,j,n)} \text{ THEN Wait ELSE Attempt} \quad (14)
\]

After determining that the weights of the criteria are sufficient, the two values are arithmetically compared in order to determine the desired decision.

IV. NUMERICAL EXAMPLE

We will consider a six-month project of a social nature. The project may begin in the first or second half of 2013. Its cost is 400 thousand PLN. After its implementation, financing in the amount of 100 thousand euros will be obtained. In addition, if the project proves to be purposeful, continued co-operation is possible with the financing institution. The purposefulness of the project depends on the development of the level of unemployment. If the level becomes high, the project will be purposeful. If the unemployment rate drops, its implementation will be useless.

A. Build a decision tree (D-Tree)

The project can be launched at the beginning of 2013 or in July 2013. The decision tree is shown in Fig. 1.

B. Build a lattice of state variables (X-Tree)

In this example, we have two state variables, \( X_1 \) - the EUR/PLN exchange rate and \( X_2 \) - the unemployment rate. These were evaluated based on historical data. Scenarios of the evolution of these indicators as an X-tree are shown in Tables I and II.

<table>
<thead>
<tr>
<th>( X_1 )</th>
<th>0</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
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<td>4.1548</td>
<td>4.2150</td>
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<td>4.0344</td>
<td>4.0946</td>
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<td></td>
<td></td>
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<table>
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</tr>
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<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td>9.6</td>
</tr>
</tbody>
</table>

C. Build a tree of the project values (V-Tree)

According to (2), we define values as in the end nodes:

- For the first state variable, the end value is equal to 100 thousand EUR multiplied by \( X_1 \), minus costs equal to 400 thousand PLN if the project was completed. The end value is equal to 0 if the project was not completed.

- For second state variable, the value is equal to 10.0 if the unemployment rate is higher than 10% and 0.0 if it is less than 10%.

The calculated values are shown in the first row and the last column of Table III. Previous values were calculated from (3) for the EUR/PLN exchange rate and from (6) for the unemployment rate. Probabilities for state variables, calculated from historical data, are equal:

- For the first state variable, the EUR/PLN exchange rate, we have \( \pi_{u} = 0.447 \) and \( \pi_{d} = 0.553 \)

- For the second state variable, the unemployment rate, we have \( \pi_{u} = 0.625 \) and \( \pi_{d} = 0.375 \)

The value tree shown in Fig. 4 is presented in Table III. The calculations assumed a risk free rate \( r \) equal to 4%.

<table>
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<td>10</td>
</tr>
<tr>
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<td>9.5</td>
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<td>9.5</td>
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<tr>
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<td>10</td>
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<td>10</td>
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<td>0</td>
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</tr>
<tr>
<td>6.25</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
D. Determine effective transitions (decisions)

Determining the effective decision after the first period is obvious. All evaluations of the project for the decision Wait are dominated by the decision Act. It is preferable in this situation to begin the project. Also, at the beginning of the year, an estimated project value vector for the decision Act dominates the calculated vector for the decision Wait. In this situation, the only right decision is to start the project at the beginning of the year.

V. CONCLUSIONS

This paper presents the outline of the valuation method of development projects in which there are real option situations. The proposed method takes into account the dependence of the project as a result of two independent random factors, which are called state variables. It is based on binomial trees and uses multi-criteria dynamic programming. Its use should allow not only the possibility to make the right decisions about a project, but also the possibility to support decision making during its implementation.

The presented method shows a high sensitivity to the adopted final value function. In the case of economic factors, the form of this function is obvious, whereas in the case of other factors, this is a utility function. Determining this function should be the subject of further research.

ACKNOWLEDGMENT

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REFERENCES


Many thanks for your participation!

We hope to see you at

World Congress on Sustainable Technologies (WCST-2014)
www.wcst.org

Have a great trip back home….!!!