

Preface

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Back in 1950's, who would have thought a social psychologist method is now famously studied and applied for computation solutions in wide global problems. I had a keen in non-linear functions since my familiarity with econometrics modelling and business information systems training at Taylor's Institution Malaysia. The Particle Swarm Optimization (PSO) methodology is one genetic algorithm that was intensively researched at the Department of Automation (Tsinghua University). I admire these scholar(s) perspectives in neural networks design – a rising interest for the optimization of energy management systems. When I reflect back on the success of Silverlake Systems - a successful Japanese-founded IT company which I was personally involved with during the development of programming projects, I came to also appreciate more the 40+ years research by Rikiya Abe. I dedicate a portion of my research to him, after learning from his shares of his personal endeavours of his work, and interesting views of digitalisation in energy markets. I found that Kennedy and Eberhart highly cited paper - "Particle Swarm Optimization" is an important example of interdisciplinary collaboration. To which I cherish such collaboration, equally by proposing this theme research with Professor Pedro Moura; whom I came to learn more about energy planning design from his course. Through my extensive research and literature review, I came to learn of the active projects and a list of contribution at ISR; which I can appreciate in both scientific innovation and from a positive interaction with long experienced and helpful Professors during the in-class sessions.

More importantly, this preliminary workshop formatted paper was a natural *deep dive activity* with experienced 'optimization' scholars, and to share my personal support for the call of contribution by the workshop organizers. This event gave me positive interactions, and provided us useful feedbacks post-presentation. Since departing from this research agenda, today - much further research remains to be conducted on this simple case studies and the PSO methodology. This method has succeeded to be a simple, robust, and explorative algorithm. Much large corporations have provided us evidence of using this technique for their software(s). Their case studies served an important preliminary assessment step to understand useful modelling features that can be applied as a future decision support system in the energy markets. After several review revisions, the analytic illustrations that I designed and integrated became a useful communication tool to the less technical audience to explore computational themes.

A large section of this workshop participation event coincided with the program schedule of 1 committed course session (attributable to a MSc.). The authors appreciated the permission granted for a 30 minutes expense - to deliver the final expected outcomes for this workshop event.

Particle Swarm Optimization in Virtual Power Plants with Cogeneration Systems

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Abstract: Network congestions within the decentralized electric grid systems calls for integrated approaches that provide power supply with reliability and security. Nowadays, among various solutions, Virtual Power Plants (VPP), which operate on the basis of advanced Information and Communication Technology (ICT) tools, are making headlines as the main conceptual solution in aggregating both demand and supply side of the energy market. Despite this development, additional challenges still exist due to the intermittency of renewable power supply and the variable energy demand. For instance, the occurrence of simultaneous charging in electric vehicles at the distribution power transformer. For this reason, the potential integration of Particle Swarm Optimization Algorithms (PSO), as an auxiliary to address the complexities of distribution network in VPP, is assessed in this paper. PSO as a distinct form of meta-Evolutionary Algorithm, have the capability to achieve flexible optimization tasks through stochastic processes. Following to the current problem of optimizing large variables in an electric grid system, case studies highlighting renewed approaches to using PSO in various fields are assessed. In effort to maximize revenue through strategic asset resource allocation and cost reduction within the electrical grid; the benefits of exploiting Combined Heat and Power (CHP) technologies are represented in the mentioned case studies. Simultaneously, CHP provided relevance for PSO to tackle the complex processes which provide well informed final decisions in addressing the demand response transition of the electric grid system. Obtained results, through literature review of the overall cycle of CHP and potential of VPP, assessed the maximization of the energy reserves within the electric grid. Taking into account such results, a methodology based on a PSO algorithm is adapted to optimize the technical and operational processes concerning the utilization of available energy reserves in a VPP. The review of the most represented PSO based approaches that have been applied to tackle such systems provided further research to improvise the strength of PSO to deliver high performance multimodal optimization solutions.

1. INTRODUCTION.

The transition of energy mix with the aim to be based on renewable energy sources places a greater focus on development of optimization solutions that exploits revenue for both demand (*consumer*) and supply side (*utilities and plant operators*) in balancing the electricity market and minimize waste heat and energy losses. However, new resources such as energy storage and electric mobility facilitates a self-healing intelligent electric grid. Heterogeneous system environments however necessitate a comprehensive range of energy management system that processes energy consumption and generation data in real-time. This ensures the optimized operation of decentralized energy resources, as well as enabling transparency in coordination between participation in operating reserves market. Virtual Power Plants (VPP) systems are capable of forecasting and profiling an aggregation of customers (e.g. industrial, residential, and commercial) with specific segmentation under demand response or demand side management programs [1]. The flexibility to classify customers based on real-time consumption and generation capacity facilitates optimal dispatching of energy while accounting price responsiveness occurring between market participants.

Research had shown that 10% to 20% of fuel savings are achievable through cogeneration and up to 40% energy efficiency in industrial plants is achieved through the optimized pairing of heat and power generation [2]. In efficiently recovering waste heat from regenerative rankine cycle based systems (e.g. diesel engines or thermal boilers), an optimization algorithm technique to optimize the operating performance of a cogeneration VPP is considered to fulfill exergy efficiency. In practice, the variation tendency in energy generation of contemporary renewable energy plant (e.g. wind and photovoltaics) provide constraints for a robust electric grid. Coupled with the evolution of plug in charging vehicles and islanding operation of micro-grids; maximizing the benefits of energy reserves through the use of efficient control mechanisms such as PSO facilitates the allocation of optimal energy generation and electricity transmission within low computational time. Thus, this study purpose is to review existing status of cogeneration and the future prospective of particle swarm optimization (PSOs) modeling, as a tool within the energy management systems in Virtual Power Plants (VPP). Based on this assessments, the self-organizing ingenuity architecture of the PSO provides an exemplary swarm-driven optimization solution model to fulfill an efficient and reliable electric grid infrastructure. The presented case studies, enriches a knowledge source for further analysis among plant operator, utilities, aggregators, and consumers in the smart grid systems to play dual role in energy dispatch. This paper is organized as follows: in the next section, academic scholar reviews and recent proposals concerning PSO model are highlighted. The third section present the case studies of existing virtual power plants integrated with cogeneration systems. In the fourth section, a proposed model of integrating PSO with a VPP scenario case is presented. Finally, final remarks are drawn in the last section of the paper.

2. LITERATURE REVIEW.

Recent modifications to the original particle swarm optimization (PSO) algorithm [1,3] were developed to improve the computation of time and performance accuracy in achieving a more efficient rate of convergence to the desired solution. Lin et al. (2015) concluded that PSO is a form of evolutionary algorithm that operates at low memory space and CPU speed [4]. Concurrent developments such as Improved Particle Swarm Optimization (IPSO), as well as Hybrid Particle Swarm Optimization (HPSO) [5,6] have been adopted to solve numerous problems concerning the risk-limiting dispatch, economic dispatch, and time. From the simulation of those new developments, the concluding research proved that nonlinear self-adapting framework for solving specific objective functions is more effective as compared to contemporary methods as studied by Liu et. al. (2017) [1].

Further evolutionary computation techniques, such as Quantum Particle Swarm Optimization (QPSO), as assessed by Hadar et al. (2016), proposed the integration of a heuristic repair operator utilizing problem-specific knowledge within the QPSO function which ensures the search process of the particles will be consistently guided via a feasible solution space [7]. Based on these properties, the roots in genetic algorithm (GA) of PSOs strategies to operate optima search test for power plants highlight its feasibility to address complex optimization of various parameters. Hence, the application of PSO in Virtual Power Plants (VPP), namely in cogeneration cases is investigated in this paper to extract the effectiveness of PSO implementation. The integration of VPP in the energy wholesale market pave the way for flexible controlling load systems which engages a more prudent and accurate allocation of unaccounted energy.

Figure 1 illustrates VPP domains that leverages the non-linear system to a comprehensive modelling and simulation tool.

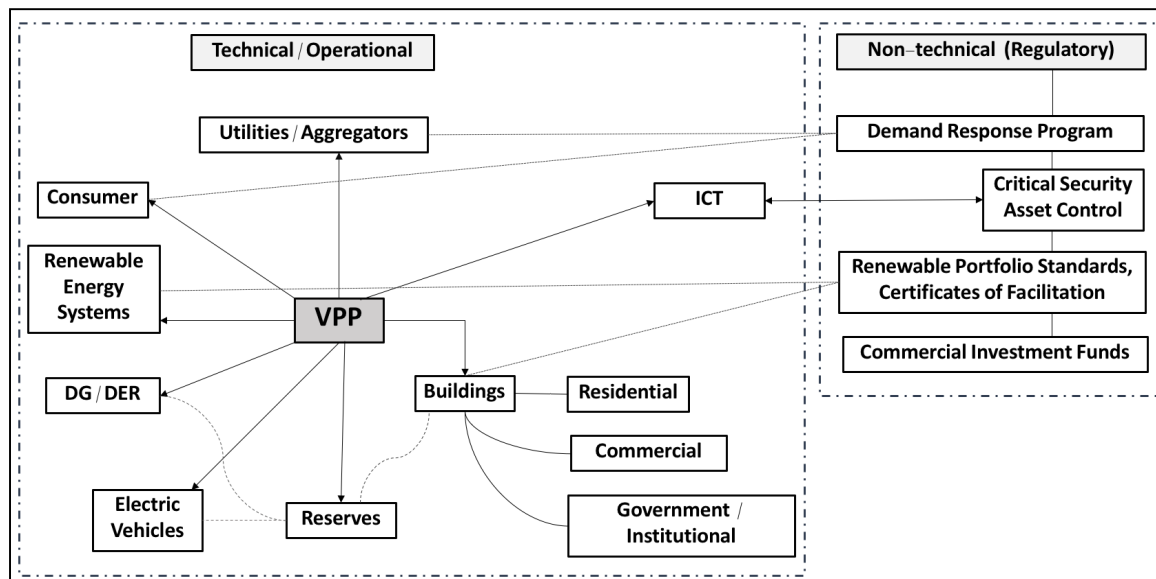


Figure 1. Topology of Virtual Power Plants

3. CASE STUDIES.

The integration of Combined Heat Power (CHP) with Virtual Power Plant systems stabilizes the power grid by enabling the increase of power generation when required and compensating power imbalances [8]. However, the load profile variation of CHP plants is dependent on seasonal heat demands. CHP allows a maximum heat recovery through identifying primary heat sources that are technically and economically effective in providing the necessary electricity power within different grid sites, as well as amongst different consumers.

Oracle reviewed the growing use of plug-in electric vehicles (PEVs) which can be used to manage intermittent supply and demand, especially in micro-site generation (*microgrid*) [9]. Thus, the integration of a network management system (*eg. Oracle Utilities Network Management System 'NMS'*) such as functioned through a VPP, will enable a microgrid controller to manage local demand, distributed generation, and energy storage assets. Oracle NMS addresses various load scenarios and aggregate the required energy supply in targeted areas through a systematic analysis that outputs the optimal mix of energy resources whereby vehicle to grid (V2G) electricity flow is accounted. Besides this, through advanced metering industry applications and meter data management systems in VPPs', Siemens integrated its smart-grid application platform "EnergyIP" as its main functioning decentralized energy management system (DEMS) [10]. The platform further optimizes grid resilience and ensures the grid stability adjusting parameters in alternating voltage and frequency options. Nikonowicz and Milewski (2012) suggests the optimization structure for CHP as described in figure 2. In cases where energy storage is integrated in the electric grid system, the optimization structure should consider price signals fluctuations between available energy storage and utility or main energy distribution prices [11]. In this case, the CHP is no longer restricted by the heat and electricity demand.

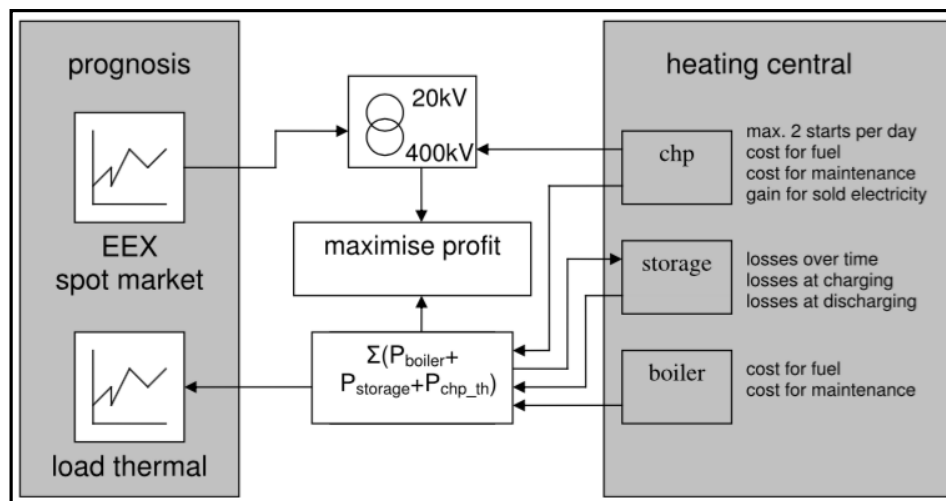


Figure 2. CHP Optimization Algorithm Structure [11].

Pickard and Strobelt (2016) reviewed Siemens FlexRamp technology which embeds the use of gas and steam turbines in an energy storage facility [2]. This boosts overall load-change gradient in brief time span as a supplementary energy capacity generation in demanding load fluctuations. Figure 3 illustrates the functioning attributes of VPP which consists of a portfolio of energy assets to fulfill the capacity demand whereby PSO reiterates the best solution path for the electric grid to jointly generate heat and electricity with minimum energy losses. The

ability to use assets, such as cogeneration plants and electric vehicles to provide swift supplementary energy generation with efficiency had been explored [8,13,14] and implemented in various VPP projects [9,10,12,18].

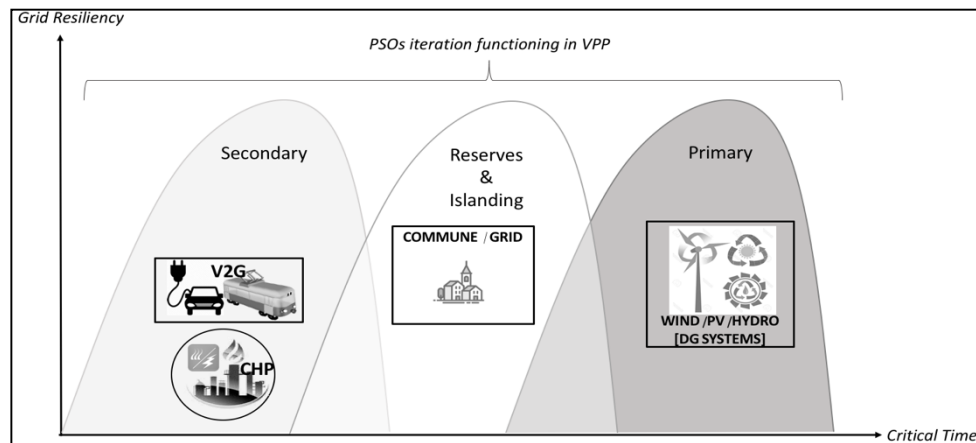


Figure 3. Cogeneration, energy reserves, and PSOs in stabilizing grid.

Later works [15,16] have reviewed the efficiency of accounting both demand planning (operational) and scheduling (technical) through build up VPP with cogeneration. The aggregation of intelligent control to forecasts future energy demand and energy tariffs allows a better utilization of installed capacity while reducing unit production costs. Figure 4 shows different interconnected control schemes whereby PSO clusters parametrize different load profiles of energy consumption, as well as manages the highest performance DER and energy reserves.

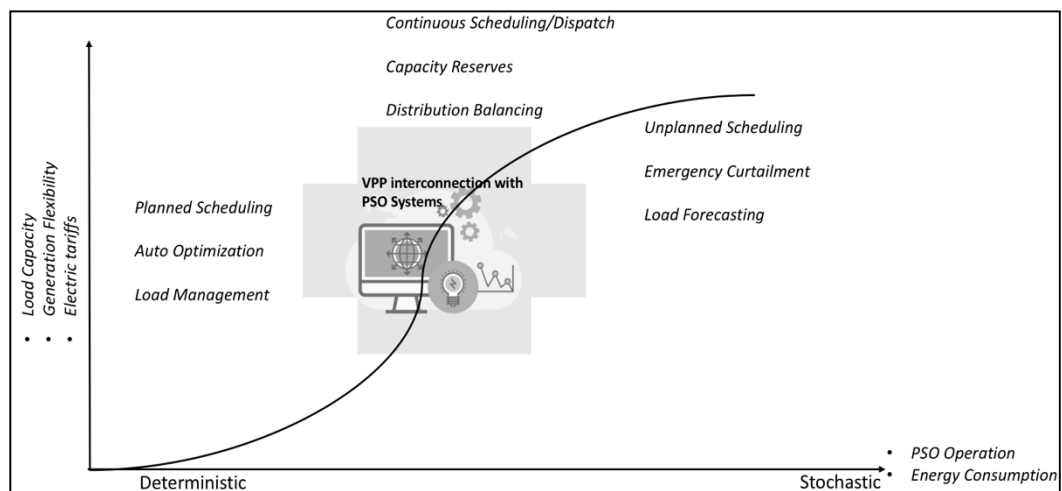


Figure 4. Interconnection of PSO Control Schemes in VPP

4. ROLE OF PSOS' AND ENERGY RESERVES WITHIN VPPS'

Auto optimization involves the implementation of a fully-fledged demand response system for load aggregation and management. However, distribution networks will require more capability to accommodate high volume of directly connected generators. Figure 5 illustrates the reiteration of best solution within the VPP parameters in reviving an existing grid flow problem (p) with generation intermittency. Cogeneration availability to transfer additional energy supply within the electric grid, as current research [13,15] had proposed, or by storing surplus energy in reserves for future energy demand, improves the optimization process. The PSO also weigh the optimal cogeneration of different microgrids or islanding community which are able to transfer energy to counterbalance the grid reliability and efficiency in Commune A.

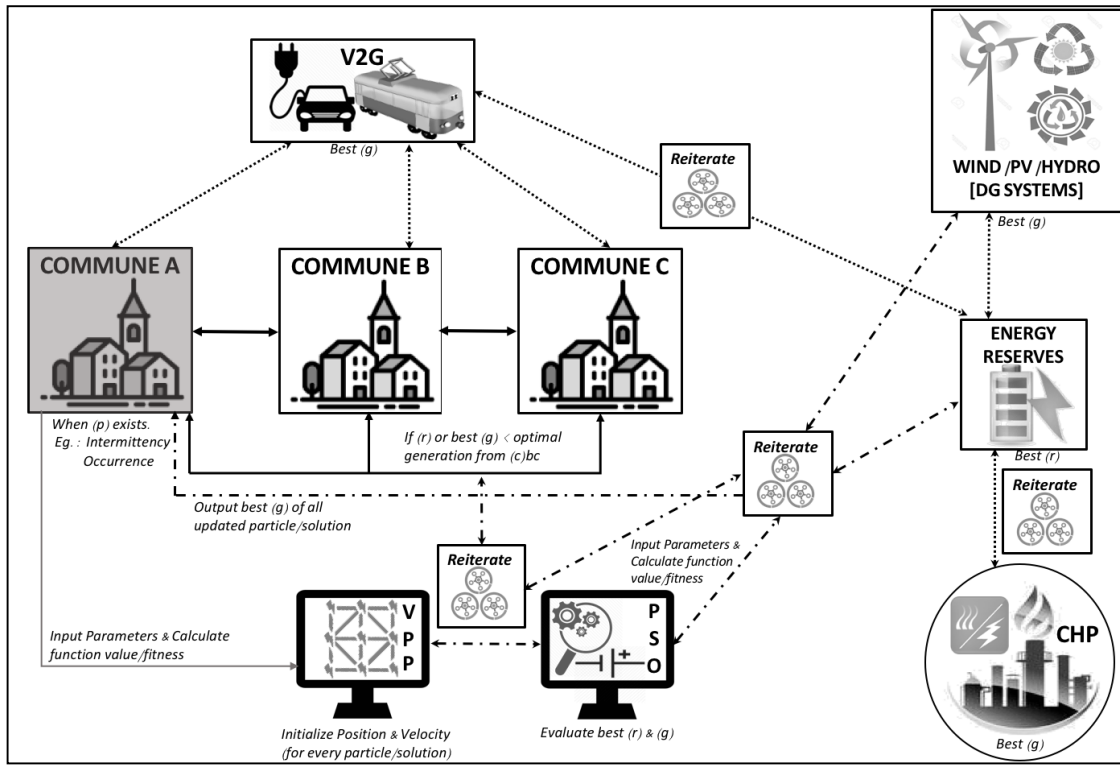


Figure 5. Schematic Diagram of PSOs in VPP when a Power Disparity Exists.

Given the scenario in figure 5, the optimizing parameters of PSO under various VPP operating conditions accounts for the fitness evaluation of the best solution to transfer energy for commune A. The required energy demand in commune A should balance with the optimal values of energy generation sourced from DG systems, CHP, energy reserves, electric mobility, or a sharing transmission from other micro-grids such as Commune B and Commune C. Simultaneously, the PSO reiterates the shift in load capacity and performs the highest performance energy generation to fulfil any intermittency occurrence or grid constraints in a short time.

4. FINAL REMARKS.

On account of the variable energy generation of renewable energy sources and disequilibrium of electric grid market, this paper establishes a study through exemplary case studies to verify the effectiveness of PSO from the development of cogeneration and Virtual Power Plants nature. The proposed optimization adjustment strategy for grid balancing utilizes the maximum energy generation value in the following three aspects of smart grid systems: cogeneration, plug in vehicle, and energy storage. VPP projects integrated with cogeneration underway, provided evidence of applying an adaptive operation tool system, such as underpinned by 'swarm planning systems' to coordinate the overall fitness of every electric grid operation ratio and better anticipate the fluctuations in power transmission. Applying the proposed optimization solution as part of the energy management systems in a given scenario basis, will sets parameters for future development with regards to the formation of PSO algorithm to aggregate the information (e.g. electricity profile or frequency control) in VPP. The capability to test the robustness of applying PSO in cogeneration systems, calls for further analysis through the use of specific software tools that encodes the decision flow and altering processes that occurs in PSO architecture.

REFERENCES

- [1] Liu, T., Jiao, L., Ma, W., Shang, R., 2017. Quantum-behaved particle swarm optimization with collaborative attractors for nonlinear numerical problems. *Communications in Nonlinear Science and Numerical Simulation* 44, 167-183. doi:10.1016/j.cnsns.2016.08.001
- [2] Pickard, A.Strobel, F., 2016. Development trends in cogeneration and combined heat and power plants. [Online]. pp.7-16. Available from: <https://www.siemens.com/content/dam/internet/siemens-com/global/products/services/energy/pg/power-plants/combined-heat-and-power/development-trends-in-cogeneration-and-combined-heat-and-power-plants.pdf> [Accessed: 7 September 2017].
- [3] Basu, A., Chowdhury, S. & Chowdhury, S. (2010) Impact of Strategic Deployment of CHP-Based DERs on Microgrid Reliability. *IEEE Transactions on Power Delivery*. [Online] 25 (3), 1697-1705. Available from: doi:10.1109/tpwrd.2010.2047121.
- [4] Lin, L., Guo, F., Xie, X., Luo, B., 2015. Novel adaptive hybrid rule network based on TS fuzzy rules using an improved quantum-behaved particle swarm optimization. *Neurocomputing* 149, 1003-1013. doi:10.1016/j.neucom.2014.07.033
- [5] Sayyaadi, H., Babaie, M., Farmani, M., 2011. Implementing of the multi-objective particle swarm optimizer and fuzzy decision-maker in exergetic, exergoeconomic and environmental optimization of a benchmark cogeneration system. *Energy* 36, 4777-4789. doi:10.1016/j.energy.2011.05.012
- [6] Jeyanthi, P.Devaraj, D., 2016. Hybrid Particle Swarm Optimization for Multi-objective Reactive Power Optimization with Voltage Stability Enhancement. *ACEEE International Journal on Control System and Instrumentation* 2, 12-15. doi:01.IJCSI.02.02.42
- [7] Haddar, B., Khemakhem, M., Hanafi, S., Wilbaut, C., 2016. A hybrid quantum particle swarm optimization for the Multidimensional Knapsack Problem. *Engineering Applications of Artificial Intelligence* 55, 1-13. doi:10.1016/j.engappai.2016.05.006

- [8] Houwing, M. & Ilic, M. (2008) The value of IT for virtual power plants with micro cogeneration systems. *2008 IEEE International Conference on Systems, Man and Cybernetics*. [Online] Available from: doi:10.1109/icsmc.2008.4811241 [Accessed: 10 September 2016].
- [9] Oracle, (2016) *Oracle Solutions for Smart Grid : Technical and Applications for your Utility's Future*. [Online]. pp.6-24. Available from: <http://www.oracle.com/us/industries/utilities/solutions-smart-grid-br-194388.pdf> [Accessed: 7 September 2016].
- [10] Siemens, (2016) *Siemens launches new generation of a virtual power plant on the market*. [Online]. Available from: <http://www.siemens.com/press/pool/de/pressemitteilungen/2016/energymanagement/PR2016020157EMEN.pdf> [Accessed: 1 September 2016].
- [11] Nikonowicz, L. & Milewski, J. (2012) Virtual Power Plants – general review: structure, application and optimization. *Journal of Power Technologies*. 92 (3), 135-149.
- [12] Sudeikat, J. & Heitmann, O. (2013) *Towards Modular Assembling of Virtual Power Plant Control Systems – The Smart Power Hamburg Platform*. In: [Online]. 2013 Aachen, Shaker Verlag. Available from: <http://enviroinfo.eu/sites/default/files/pdfs/vol7995/0188.pdf> [Accessed: 8 September 2016].
- [13] Basu, A., Chowdhury, S. & Chowdhury, S. (2009) Strategic deployment of CHP-based distributed energy resources in microgrids. *2009 IEEE Power & Energy Society General Meeting*. [Online] Available from: doi:10.1109/pes.2009.5275186 [Accessed: 18 September 2016].
- [14] EDISON, (2011) *Review on Integration of distribution Energy Resources (DER) in Power Systems*. [Online]. pp.5-9. Available from: http://www.edison-net.dk/~media/EDISON/.../WP2.1.1_Review_DER_intergration.ashx [Accessed: 6 September 2016].
- [15] Braun, M., Seijo, S., Echanobe, J., Shukla, P., del Campo, I., Garcia-Sedano, J., Schmeck, H., 2016. A neuro-genetic approach for modeling and optimizing a complex cogeneration process. *Applied Soft Computing* 48, 347-358. doi:10.1016/j.asoc.2016.07.026
- [16] Siddaiah, R.Saini, R., 2016. A review on planning, configurations, modeling and optimization techniques of hybrid renewable energy systems for off grid applications. *Renewable and Sustainable Energy Reviews* 58, 376-396. doi:10.1016/j.rser.2015.12.281
- [17] Dohmen, F. (2014) Virtual Power Stations. *Der Spiegel*. [Online]. (49) pp.2-3. Available from: http://www.lichtblick.de/docs/default-source/infomaterial/spiegel_virtual-power-plants_engl.pdf?sfvrsn=2 [Accessed: 11 September 2016].
- [18] Altran, (2014) *Flexibilities - a necessity for an affordable future energy system*. [Online]. pp.2-13. Available from: http://www.altran.com/fileadmin/.../Altran_Whitepaper_VirtualPowerPlant_141126.pdf [Accessed: 11 September 2016].