Paper ID #16118

Effect of Electrical Alternative Energy Sources on Power Grid

Dr. Masoud Fathizadeh P.E., Purdue University - Calumet

Masoud Fathizadeh – PhD, PE Professor Fathizadeh has been with the Department of Electrical and Computer Engineering Technology Purdue University Calumet since 2001. He has worked over 15 years both for private industries and national research laboratories such as NASA, Argonne and Fermi National Laboratories. Dr. Fathizadeh has established his own consulting and engineering company in 1995 specializing in power system, energy management and automation systems. During last twenty years the company performed many private and government projects. Dr. Fathizadeh has published numerous journal, conference and technical articles. He has been instrumental figure in establishing mechatronic engineering technology at Purdue University Calumet. His areas of interests are, control systems, power systems, power electronics, energy, and system integration. Dr. Fathizadeh is a registered professional engineer in the State of Illinois.

Mr. Uditha Sudheera Navaratne, Purdue University - West Lafayette

Uditha S. Navaratne is a Ph,D. student at Purdue University, West Lafayette, Indiana, USA. He received B.Sc.(Eng.) from University of Peradeniya, Sri Lanka in 2007 and MS degree from Purdue University in 2012. His working experience include Sri Lanka Telecom, Sri Lanka and Faculty of Engineering, University of Peradeniya, Sri Lanka. His area of interest is in Smart Grid, Micro-grid, Artificial Intelligence, Neural Networks, Agent based systems and their applications in smart grid and micro-grid.

Mr. Venkatateja Koppaku

I am a graduate student pursuing masters in Electrical Engineering technology at Purdue University, Calumet, Indiana, USA. And holds a Bachelor degree in Electrical & Electronics Engineering from Acharya Nagarjuna University, India. my area of interests are Renewables and control systems.

Effect of Electrical Alternative Energy Sources on Power Grid

Abstract

Recent geopolitical unrest in the Mideast, high consumption of fossil fuel by new large industrial bodies and their environmental impacts encouraged many countries to find alternative sources of energy. Wind, solar, wave and geothermal energy have received most of the attentions in recent years. However, except geothermal energy, these energy alternatives are cyclical and cannot produce energy at any time readily and reliably. Storage systems such as battery banks have been used to store the energy for future use. One of the most widely used alternative sources for electric energy production is solar energy. Solar cells are used to harness the energy from nature and produce electricity. Solar cells are connected in series and parallel and assembled into a panel. Electric output power of solar a panel is a function of location, time of the day and season. Average daily output of a flat plate collector at latitude tilt in the contiguous United States is 3 – 7 kWh/m²/day and the performance is less in high-altitude areas like Europe. Solar cells produce direct current (DC) which must be converted to alternating current (AC) using a grid tie inverter in existing distribution grids that use AC. This incurs an energy loss of 4 – 12 percent. However, high voltage DC grid transportation has less energy waste than AC grid; so, there is a trade-off consideration in deciding to construct high voltage DC grids and apply the inverter at the consumers' end.

The behavior solar and wind generators as well as their effects on the load and power grid can be studied utilizing MATLAB-SIMULINK®, commercially available DIgiSILENT® PowerFactory and Homer software. MATLAB-SIMULINK® can readily perform calculation and simulation of individual units while the power flow and grid stability analysis can be done utilizing PowerFactory. On the other hand HOMER software package is capable of handling overall system feasibility and cost analysis. A graduate course is developed and offered to address hybrid energy and battery systems. Students in Hybrid and Battery System course are required to investigate hybrid electric systems with alternative energy sources such as wind and solar.

This paper presents:

- Modeling and simulation of solar cell panels
- Power Grid Simulation
- Voltage profile for bus
- Controlling real and reactive power via wind turbines and solar panels
- Power flow analysis results obtained from PowerFactory software
- Integration of MATLAB, Homer and PowerFactory software packages into a graduate course
- Student Survey regarding the use of Simulation Software Packages

Introduction

Growth of industrial countries in recent decades demanded a large amount of energy. Most of this energy resulted from the consumption of fossil fuel. Many countries are spending money, time and effort to find new sources of energy. However, this search was faced by many challenges, since some of these resources are expensive, destructive to the environment, or ceasing to exist in the near future. Significant progress has been made over the last few years in the research and development of renewable energy systems such as wind, sea-wave and solar energy systems. Among these resources, solar energy and wind are considered the most promising, reliable, abundant, and environment friendly renewable energy source [1, 2]. Most of these energies are dependent on parameters such as time of the day, presence of sun or speed of the wind. The energy production from these resources will be drastically affected as these parameters change. Storage systems such as battery banks are utilized to store the surplus of the produced energy from these renewable sources. Energy storage then becomes an essential component to guarantee a continuous electricity delivery. The most widely used manner of storage for Photovoltaic (PV) structures is the battery banks, due to the fact that it is cheap and simple to manufacture, it has a mature, reliable, and well-understood history and if used properly, it can last quite long at an affordable price. Its self-discharge is substantially low and it requires a low cost and affordable protection system [1, 2].

Battery power storage is also utilized to reduce the output fluctuation of the whole hybrid system. Power management of the entire machine and electricity go with the flow among structures and grids are primarily based on the power electronics interface. The battery energy storage system mitigates fluctuating electricity generated from PV array, and injects much less fluctuating output into the grid. The reduction of the power fluctuation from renewable energy sources contributes into a more stable voltage and power delivery to the grid and consequently low harmonic and better power factor for the overall power system [3].

Photovoltaic power generation employs solar panels composed of a number of solar cells containing a photovoltaic material. Materials presently used for photovoltaics include monocrystalline silicon, polycrystalline silicon, amorphous silicon, cadmium telluride, and copper indium gallium selenide/sulfide. Photovoltaic solar panel is the most commonly used solar technology to generate electric energy. Electricity produced from PV array is minimal at night and is greatly reduced under cloudy conditions. Therefore, a storage or complementary power system is required. Solar electricity production depends on the limited power density of the location's insolation.

In commercial applications, PV array is first linked to the commonplace DC bus by using a boost converter, where the battery is also related with a bi-directional DC/DC converter, and then integrated into the alternating AC grid by using a common DC/AC inverter. Maximum Power Point Monitoring (MPPT) enables PV array to generate the maximum power to the grid, and the battery electricity storage can be charged and discharged to balance the energy between PV and grid. It is demonstrated that controlling real power via solar panels, results in a better response as compared to controlling the reactive power [4].

In this paper, a photovoltaic hybrid generation mechanism is studied and simulated. A hybrid electric system provides a greater quality electricity generation since the system is not solely dependent on one type of energy source. Whilst some of these devices may shutdown the alternate source still can deliver the electricity.

Case Study

In order to study power system behavior and operating conditions of different generators, buses, transformers, motors and loads in a system, power analysis and load flow calculations must be performed. The flow of active and reactive power is known as load flow or power flow. Load flow is an important tool used by power engineers for planning and determining the best operating conditions for a power system and exchange of power between utility companies. Load flow studies provide steady state analysis to determine the various bus voltages, phase angles, active and reactive power flows through different branches, generators, and transformers. The power system is modeled by an electric circuit which consists of generators, transmission network and distribution network [5]. The behavior of these generators as well as their effects on the load and power grid can be studied utilizing MATLAB-SIMULINK® [6] and commercially available DIgiSILENT® PowerFactory software. MATLAB-SIMULINK® can readily perform calculation and simulation of individual units while the power flow and grid stability analysis can be done utilizing PowerFactory software. Students in the Hybrid and Battery System course are required to simulate the standard IEEE-9-Bus system using both MATLAB-SIMULINK and PowerFactory software. The layout for the 9-Bus power system is shown in Figure-1. The data page configuration for generator at bus-3 is shown in Figure-2.

The simulation result of the IEEE-9-Bus system using MATLAB-SIMULINK is shown in Table-1. In this table the real and reactive powers at each bus are given. All generators are conventional thermo-generator using conventional fossil fuel. The generator at burs-3 is replaced with a photovoltaic generator and the result of a simulation is shown in Table-2. It can be seen that the values of real and reactive powers at different buses are somewhat similar.

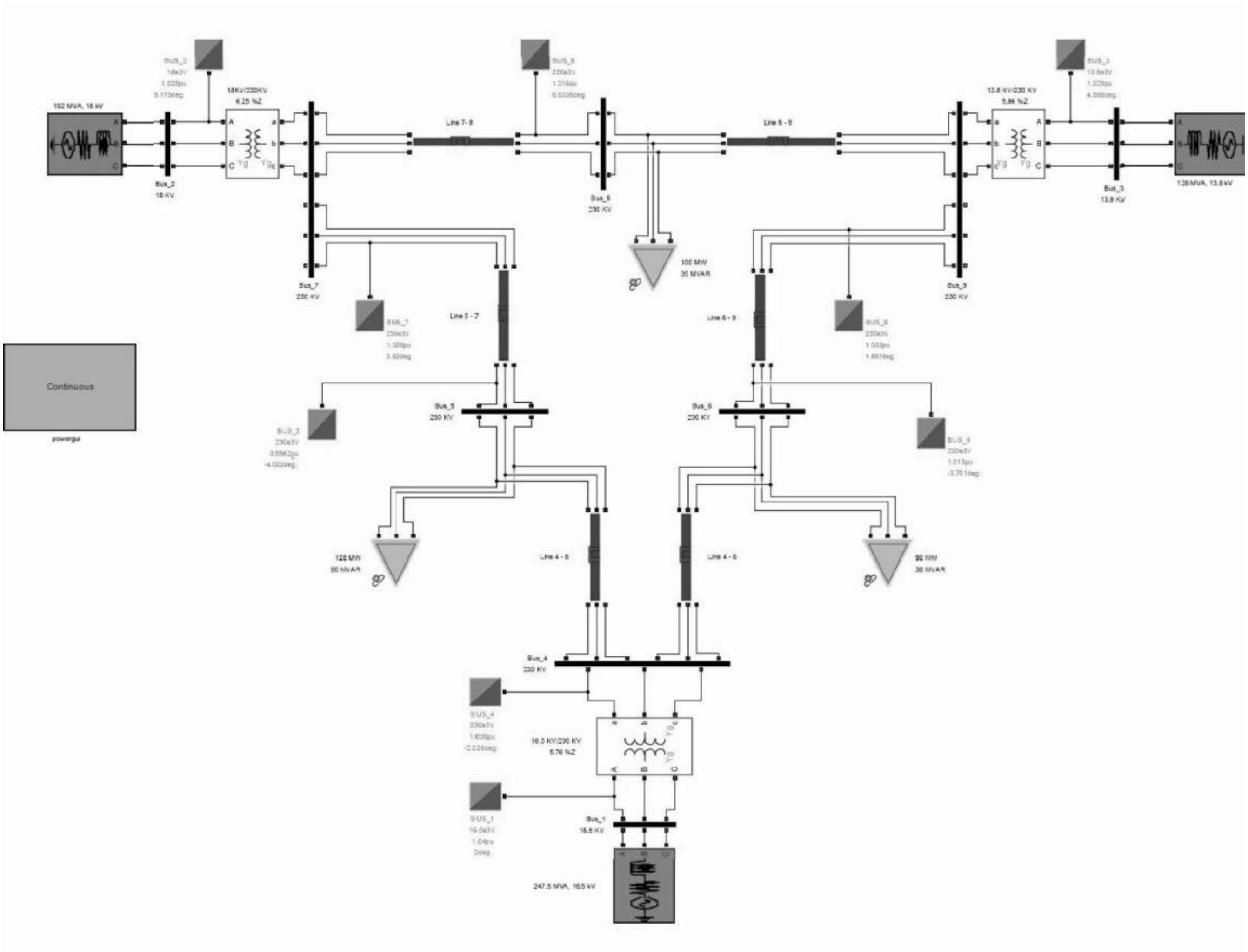

Figure-1 Graphical layout of IEEE-9 Bus System

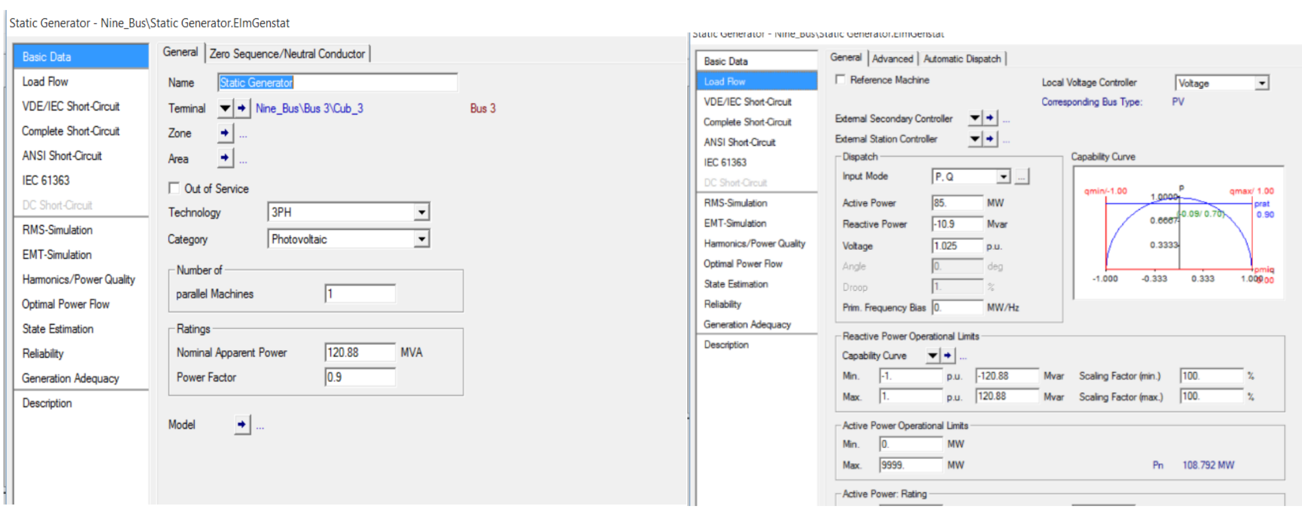

Figure-2 Data input page for generator connected to Bus-3 for regular generator and PV system

The simulation of the same system is also performed utilizing Power Factory Software. Similar results obtained from both MATLAB and Power Factory. The results from PowerFactory is shown in Table-3.

Table-1 Real and Reactive power at 9-buses

	BUS_1 V= 1.040 pu/16.5kV 0.00 deg ; Swing bus		BUS_2		BUS_3		BUS_4		BUS_5		BUS_6		BUS_7		BUS_8		BUS_9	
	P(MW)	Q(Mvar)	P(MW)	Q(Mvar)	P(MW)	Q(Mvar)	P(MW)	Q(Mvar)	P(MW)	Q(Mvar)	P(MW)	Q(Mvar)	P(MW)	Q(Mvar)	P(MW)	Q(Mvar)	P(MW)	Q(Mvar)
Generation	71.645	26.99	163	6.64	85.00000175	-10.87	0	0	0	0	0	0	0	0	0	0	0	0
PQ Load	0	0	0	0	0	0	8.10574E-08	-1.58826E-06	124.9999952	49.99999883	90.00000201	29.99999772	6.24093E-06	-1.282E-05	100	34.99999919	-2.72162E-06	-1.2262E-05
Z shunt	0.216323779	0.216316243	0.210128385	0.210121637	0.210128609	0.210121413	-3.65536E-06	3.65561E-06	2.84356E-12	-3.49587E-12	-5.52891E-12	7.65255E-12	-3.36753E-06	3.36775E-06	4.1555E-13	5.65592E-12	-3.63775E-06	3.638E-06
BUS_1							-71.64	-23.87										
BUS_2													-163	9.19				
BUS_3																	-85.14	14.97
BUS_4	71.64	26.99							-40.63	-38.65	-30.58	-16.54						
BUS_5							40.89	22.84					86.67	-8.39			60.77	-18.08
BUS_6							30.75	1.03										
BUS_7			163	6.64					-84.37	-11.35					-75.86	-10.71		
BUS_8													76.33	-0.8			24.23	3.11
BUS_9					85	-10.87					-59.42	-13.46			-24.14	-24.29		

Table-2 Real and Reactive power at 9-buses with PV Generator at Bus-3 Using MATLAB

	BUS_1 V= 1.040 pu/16.5kV 0.00 deg ; Swing bus		BUS_2		BUS_3		BUS_4		BUS_5		BUS_6		BUS_7		BUS_8		BUS_9	
	P(MW)	Q(Mvar)	P(MW)	Q(Mvar)	P(MW)	Q(Mvar)	P(MW)	Q(Mvar)	P(MW)	Q(Mvar)	P(MW)	Q(Mvar)	P(MW)	Q(Mvar)	P(MW)	Q(Mvar)	P(MW)	Q(Mvar)
Generation	71.645	26.99	163	6.64	85	-10.87	0	0	0	0	0	0	0	0	0	0	0	0
PQ Load	0	0	0	0	0	0	8.11E-08	-1.60E-06	125	50	90	30	6.24E-06	-1.30E-05	100	35	-2.70E-06	-1.20E-05
Z shunt	0.216324	0.216316	0.210128	0.210122	0.210129	0.210121	-3.70E-06	3.66E-06	2.84E-12	-3.50E-12	-5.50E-12	7.65E-12	-3.40E-06	3.37E-06	4.16E-13	5.66E-12	-3.60E-06	3.64E-06
BUS_1							-71.64	-23.87										
BUS_2													-163	9.19				
BUS_3																	-85.14	14.97
BUS_4	71.64	26.99							-40.63	-38.65	-30.58	-16.54						
BUS_5							40.89	22.84					86.67	-8.39				
BUS_6							30.75	1.03									60.77	-18.08
BUS_7			163	6.64					-84.37	-11.35					-75.86	-10.71		
BUS_8													76.33	-0.8			24.23	3.11
BUS_9					85	-10.87					-59.42	-13.46			-24.14	-24.29		

Table-3 Real and Reactive power at 9-buses with PV Generator at Bus-3 Using PowerFactory

	BUS_1 V= 1.040 pu/16.5kV 0.00 deg ; Swing bus		BUS_2		BUS_3		BUS_4		BUS_5		BUS_6		BUS_7		BUS_8		BUS_9	
	P(MW)	Q(Mvar)	P(MW)	Q(Mvar)	P(MW)	Q(Mvar)	P(MW)	Q(Mvar)	P(MW)	Q(Mvar)	P(MW)	Q(Mvar)	P(MW)	Q(Mvar)	P(MW)	Q(Mvar)	P(MW)	Q(Mvar)
Generation	71.64	26.99	163	6.64	85	-10.87	0	0	0	0	0	0	0	0	0	0	0	0
PQ Load	0	0	0	0	0	0	8.11E-08	-1.60E-06	125	50	90	30	6.24E-06	-1.30E-05	100	35	-2.70E-06	-1.20E-05
Z shunt	0.216324	0.216316	0.210128	0.210122	0.210129	0.210121	-3.70E-06	3.66E-06	2.84E-12	-3.50E-12	-5.50E-12	7.65E-12	-3.40E-06	3.37E-06	4.16E-13	5.66E-12	-3.60E-06	3.64E-06
BUS_1							-71.64	-23.87										
BUS_2													-163	9.19				
BUS_3																	-85.14	14.97
BUS_4	71.64	26.99							-40.63	-38.65	-30.58	-16.54						
BUS_5							40.89	22.84					86.67	-8.39				
BUS_6							30.75	1.03									60.77	-18.08
BUS_7			163	6.64					-84.37	-11.35					-75.86	-10.71		
BUS_8													76.33	-0.8			24.23	3.11
BUS_9					85	-10.87					-59.42	-13.46			-24.14	-24.29		

Class Survey

A class survey is performed to measure the students experience with the MATLAB, PowerFactory and HOMER software packages. Twenty two (22) students took the survey 20 students had some previous experience with MATLAB, and minimal or no experience with PowerFactory and Homer software packages. Questions regarding the following seven (7) subjects are asked:

1. Previous experience with software packages
2. Capability of software for detail modelling of components
3. Capability of software for performing individual power analysis
4. Capability of software for performing grid (network) power analysis
5. Cost and economic analysis capability
6. Degree of difficulty

7. Did simulation software enhanced learning?

The result of this survey is tabulated and shown in Table-4.

Table-4 Student Survey regarding the use of Simulation Software Packages

Simulation Software	Previous Experience**	Detail Component	Power Flow	Cost Analysis	System Performance	Degree of Difficulty*	Did software help learning**
HOMER	2	No	No	Yes	Yes	2	85%
PowerFactory	1	Somewhat	Yes	No	Yes	4	90%
MATLAB	20	Yes	Somewhat	No	Yes	6	73%

* 1=Very Easy, 10= Very Difficult, **22 Students surveyed

The result from class survey revealed that students can perform their project assignments with Homer and PowerFactory software easily within the first week while MATLAB requires more time to acquire experience and competency.

Course Outline

Hybrids & Battery Technology

This is a three-credit hour graduate level course that studies different sources of energy and performs the comparison between these sources. Battery and storage technology, charging systems, and battery life cycle are studied in detail. Solar thermal systems, solar photovoltaic systems, and wind, energy systems are discussed and practical examples are given. Hybrid Systems, the need for hybrid systems, range and type of hybrid systems, case studies of diesel-PV, wind-PV, gas-PV, biomass-diesel systems, gas-electric, battery sizing and hybrid electric vehicles are given.

The course objectives are as follows:

- Understand fossil fuel based systems, impact of fossil fuel based systems, non-conventional energy – seasonal variations and availability, renewable energy – sources and features and hybrid energy systems.
- Solar thermal systems, solar radiation spectrum, radiation measurement, and power generation.
- Solar photovoltaic systems, operating principle, photovoltaic cell concepts, cell, module, array, series and parallel connections, and maximum power point tracking.
- Understand battery technology, operating principle and components of a battery, types and characteristics different batteries, selection and sizing of battery storage.
- Understand basic electrochemical equations, principles & reactions, types of cells, cell chemistries, battery configurations, hazard controls, safety features, test methods for qualification & acceptance.
- Understand the selection of the right battery choice, safe design, workable design, safety and issues with different battery chemistries and factors affecting performance of batteries.
- Understand wind, wind patterns and wind data, site selection, types of wind mills, characteristics of wind generators.

- Recognize hybrid systems, need for hybrid systems range and type of hybrid systems.

Impact on Graduate Education

The relationships between three types of commercially available software for simulation of power systems were established. Simulink/MATLAB software package has been used in the past and most of students have sufficient experience with it. However, PowerFactory and Homer software packages were introduced for the first time and students needed practice and time to get acquainted with the software package. A class survey was performed to measure the impact of PowerFactory and Homer packages students' learning. Initial assessment indicates it takes only one week for students to learn the PowerFactory and Homer software. Students within the first week of class are able to model and simulate power systems. Other factors such as student's background, attendance, workload, and familiarity with power system subjects can affect learning of new subject as well.

Conclusion

A graduate course is developed to teach the Hybrid Energy System with emphasis on battery technology. The students are required to calculate optimum photovoltaic system with inclusion of battery bank. The effect of PV generator on a standard power system network is investigated. Three software packages of Simulink/MATLB, HOMER and PowerFactory are used. MATLAB can perform detail behavior of the generators while PowerFactory software package can perform power system analysis easily and HOMER is capable of handling overall power management and financial feasibility. We use Simulink/MATLAB since this program has a battery model integrated in its library and because our students are very familiar with the program and it is widely available to the students in the full version on our campus or as student version at a very low cost and the trial version of HOMER software can be downloaded free for one month. On the other hand the PowerFactory software package is a great tool for performing load flow and power system analysis. The generator at bus-3 is replaced by a PV generator as a case study. Similar results were obtained utilizing both MATLAB and PowerFactory software tools. Students can learn PowerFactory and HOMER in less than a week and be able to model and simulate power system projects easily.

References

[1] Femia, N., Petrone, G., Spagnuolo, G., and Vitelli, M., Power Electronics and Control Techniques for Maximum Energy Harvesting in Photovoltaic System, CRC Press, 2012, pp. 1-87

[2] Barnes, F. S. and Levine, J. G., Large Energy Storage Systems Handbook, CRC Press, 2011, pp. 61-109

[3] Jeon, J., Kim, S., Cho, C., J., Kim, and J., Power Control of Grid-Connected Hybrid Generation System with Photovoltaic/Wind Turbine/Battery Sources, The 7th International Conference on Power Electronics, 22-26 October, 2007, Daegu, pp. 506-510.

[4] Chu, Y., "Review and Comparison of Different Solar Energy Technologies," http://www.geni.org/globalenergy/research/review-and-comparison-of-solar-technologies/Review-and-Comparison-of-Different-Solar-Technologies.pdf, August 2011.

[5] Mageshvaran, R., Raglend, I.J., Yuvaraj, V., Rizwankhan, P.G., Vijayakumar, T. and Sudheera, Implementation of Non-Traditional Optimization Techniques (PSO, CPSO, HDE) for the Optimal Load Flow Solution. TENCON2008-2008 IEEE Region 10 Conference, 19-21 November 2008.
[6] Salmi, T., Bouzguenda, M., and Gagtli, A., "MATLAB/Simulink based modeling of solar photovoltaic cell," International journal of renewable energy research, vol.2, no.2, 2012.