Addition and Impact of New Renewable Electrical Energy Sources on Existing Power Grid

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Abstract

Due to the increasing concern about environmental effects of fossil fuel electric energy generation, renewable energy systems and especially wind and solar energy generation have attracted great interests in recent years. The solar cell panels are used to harness the energy from the nature and produce electricity. The voltage regulating capability of Wind Turbine Generators (WTG) varies with generator technology and manufacturer. Type 1 and 2 WTGs are based on induction generators, and have no inherent voltage controllability. Type 3 and 4 WTGs involve power electronic converters, which offer the ability to regulate reactive power, and hence achieve voltage control. Wind and solar energy receiving the most attention compared to other alternatives such as fuel cell tidal and geothermal energy. The technology for both solar and wind energy is progressing with better system efficiencies every year. International conventions and agreements persuaded power industry to utilize more "green" energy. Most of alternative energies except geothermal energy are cyclical and cannot produce energy continuously without interruption. Location, time, and season of the year are major factors on the output of solar and wind energy systems. Storage and battery are good tools to offset the down time of these type of energy sources. Solar cells convert the energy from nature and produce electricity. Solar cells are assembled using series and parallel configurations and packaged into a panel. The power requirement for a facility determines the needed number of the panels. The output power of a solar panel is a function of location, time of the day and season. For instance an 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. Normally, the output of solar panels are D C and converted to AC via an inverter. Recently, Solar panels with AC output are introduced in the market where the inverter is an integral part of the panel. On the other hand, wind turbines with both DC and AC outputs are readily available. In order to connect solar panels or wind turbine outputs to the existing AC grid DC to AC conversion is required. That results an energy loss of 4 – 12 percent. High voltage DC system has less energy waste than AC grid. The design of robust and low loss system require relevant calculations for deciding to construct high voltage DC grids and apply the inverter at the consumers' end, to connect to existing AC grid.

Solar and wind generators behave differently and their performance as well as their effects on the load and power grid can be studied utilizing, commercially available DIgiSILENT® PowerFactory, MATLAB-SIMULINK®, PLEXIM® and Homer software. MATLAB-SIMULINK® and PLEXIM® 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. In this paper, we propose a hybrid electric system which mixes solar and wind turbine generator as an alternative for conventional supply of electrical generator like thermal and hydroelectric technology. 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

Because of excessive need for of power and limited availability of conventional energy resources, non-conventional sources gain a greater popularity amongst researchers. Extensive amounts of studies and research have been directed to enhance the strength and efficiency of non-traditional energy systems in recent years. Hybrid energy system uses multiple sources, extracts strength from distinct assets simultaneously, which enhances the performance. The operating of PV /Wind hybrid systems with different topologies are reported in [1, 2]. The fundamental information of PV operation, PV module, PV array and their modeling are studied in [2-4]. The operation of PV modules at varying environmental situations like sun irradiation and temperature are explained in [5-7]. Different MPPT techniques, their pros and cos and why MPPT manipulator is required is explained in [8-10].The wind energy system, its working operation and the techniques to extracts the most energy from the wind power turbines is presented in [11, 12]. The operation of bi-directional converters, the method of connection to battery for both charging and discharging is shown in [13, 14]. Renewable energy sources have emerged as a popular opportunity electric energy supply where production of electricity in traditional approaches is not realistic. During the last few years the photovoltaic and wind power energy were expanded substantially. In this paper we propose a hybrid electric system which mixes solar and wind turbine generator as an alternative for conventional supply of electrical generator like thermal and hydroelectric technology. The whole hybrid system is defined given along with comprehensive simulation to demonstrate the feasibility of the system.

Harvesting energy from sun is simplest while it is available, during the nights and cloudy days, energy from the sun is much lower and is not suitable for electric energy production. A battery energy storage system can be used to store the excess electric energy during the sunny days and use the stored energy during the nights and cloudy days. The battery power storage is vital to attain a stable and reliable output from photovoltaic (PV) electricity generation system during load variation and subsequently to enhance dynamic behaviors of the whole power grid. Renewable energy produces very little of toxic material including carbon dioxide or different chemical pollution, so it has minimal impact on the environments.

Among all the renewable energy resources, the solar and wind energies have the exceptional capability as an energy producing power source, due to their many advantages like low or zero emission of pollutant gases, low cost, inexhaustible sources and clean availability of those power resources. But, these structures have a few hazards additionally like dependency on climate conditions. One of the major negative aspects with renewable energy is that it is difficult to generate the portions of power which are as large as those produced by conventional fossil fuel generators. Therefore, it is advantageous to reduce the consumption of electricity along with locating reliable and sustainable alternative supply of electricity.

Some other disadvantage of renewable energy resources is the dependency of delivery on sun light or wind and so on. Renewable energy regularly depends on the climate circumstance for its source of energy input. A wind turbine relies upon on wind to run the turbine, and a solar cell relies upon on the placement of solar to produce energy. The energy from those resources are exceedingly unpredictable and inconsistent. The generation renewable electricity is comparably more expensive than the traditional fossil fuel technology and it lead to a substantial capital commitment. The dependency on sun or wind can be somewhat reduced by introduction of battery storage system. This paper presents a hybrid wind/PV/Battery power system for machine using MATLAB/Simulink and PowerFactory® software simulation.

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.

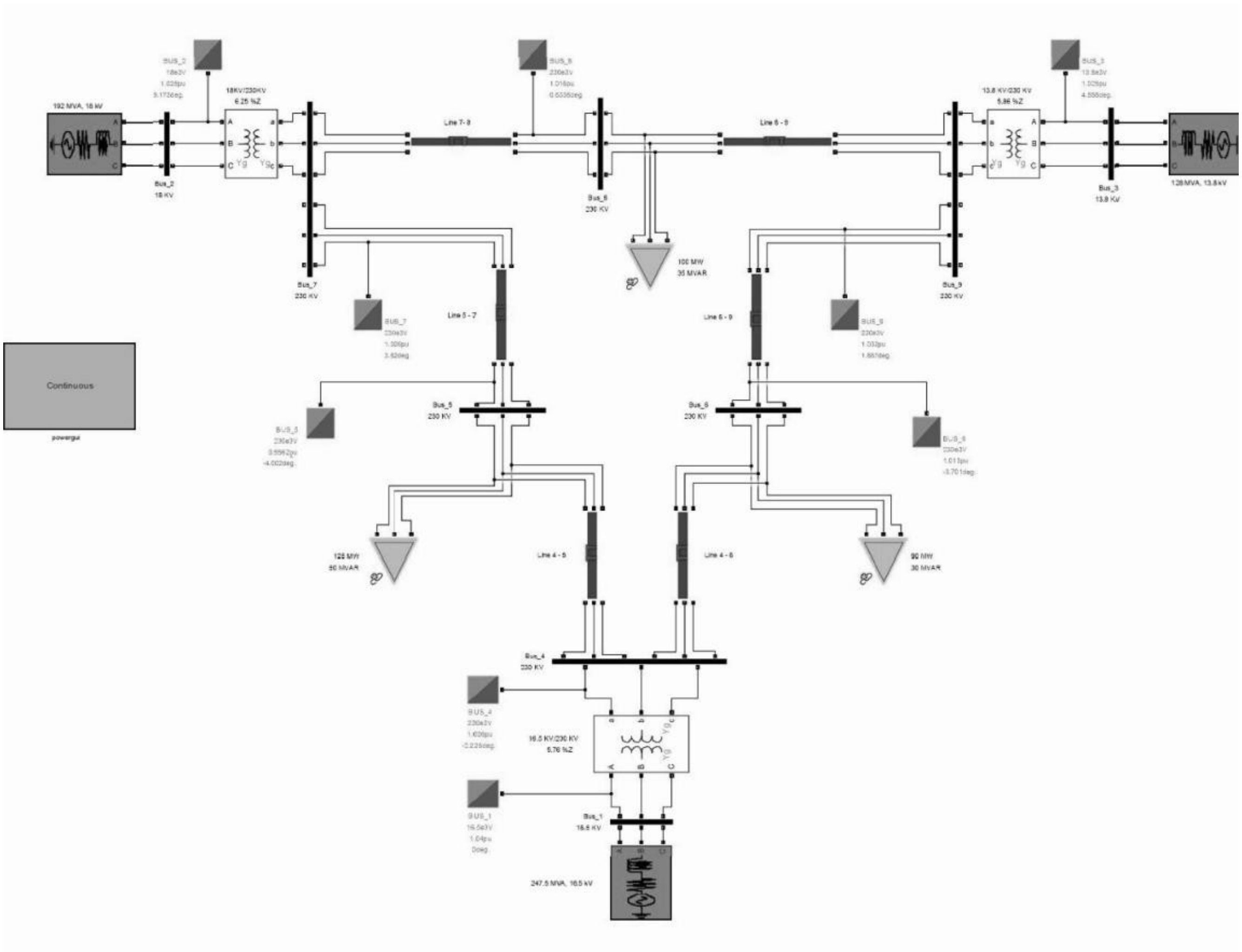

Figure-1 Graphical layout of IEEE-9 Bus System

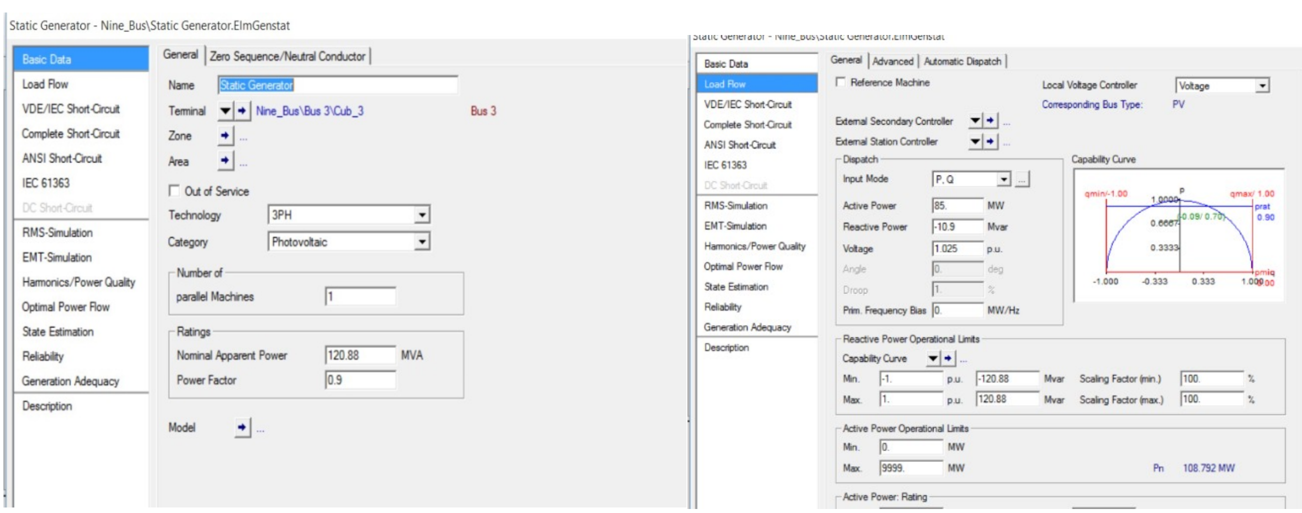

Figure-2 Data input page for generator connected to Bus-3 for regular generator and PV system

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

	P(MW)		Q(Mvar)	P(MW) Q(Mvar)	P(M W)													
Generation	71.645																	
PQ Load																		
Z shunt																		
BUS_1																		
BUS_2																		
BUS_3																		
BUS_4																		
BUS_5																		
BUS_6																		
BUS_7																		
BUS_8																		

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

	P(M	Q(Mva	P(M	Q(Mva	P(M	Q(Mva	P(MW)	Q(Mvar)	P(MW)	Q(Mvar)	P(MW)	Q(Mvar	P(MW)	Q(Mvar	P(MW)	Q(Mvar	P(MW)	Q(Mvar)
Genera	71	2	163	6.64	85	-	0	0	0	0	0	0	0	0	0	0	0	0
PQ	0	0	0	0	0	0	8.11	-	125	50	90	30	6.24	-	100	35	-	-
Z	0.21	0.21	0.21	0.21	0.21	0.21	-	3.66	2.84	-	-	7.65	-	3.37	4.16	5.66	-	3.64
BUS							-	-										
BUS													-163	9.19				
BUS																	-	1
BUS	7	2							-	-	-	-						
BUS							4	2					8	-				
BUS							3	1.03									6	-
BUS			163	6.64					-	-					-	-		
BUS													7	-0.8			2	3.11
BUS					85	-					-	-			-	-		

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

	P(M	Q(Mva	P(M	Q(Mva	P(M	Q(Mva	P(MW)	Q(Mvar)	P(MW)	Q(Mvar)	P(MW)	Q(Mvar	P(MW)	Q(Mvar	P(MW)	Q(Mvar	P(MW)	Q(Mvar)
Genera	7	2	163	6.64	85	-	0	0	0	0	0	0	0	0	0	0	0	0
PQ	0	0	0	0	0	0	8.11	-	125	50	90	30	6.24	-	100	35	-	-
Z	0.21	0.21	0.21	0.21	0.21	0.21	-	3.66	2.84	-	-	7.65	-	3.37	4.16	5.66	-	3.64
BUS							-	-										
BUS													-163	9.19				
BUS																	-	1
BUS	7	2							-	-	-	-						
BUS							4	2					8	-				
BUS							3	1.03									6	-
BUS			163	6.64					-	-					-	-		
BUS													7	-0.8			2	3.11
BUS					85	-					-	-			-	-		

Class Survey

A class survey 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.

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