

Understanding smart power grid systems by a course project

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Abstract

A smart grid system shows its advantages in the integration of renewable energy resources and distributed energy storage as well as the significant improvement in the power system's reliability, efficiency, and security. In order to illuminate the technologies in the smart grid, a model is constructed. Moreover, to evaluate the performance of a micro- grid, a performance metric is introduced to consider the electricity cost, air emissions, and customer satisfaction. One cases in a smart grid are simulated and the results are discussed.

1. Introduction

Energy is fundamental to quality of life, economic health and security. The power grid currently used consists of 16,000 power plants, around 3,300 utilities, and 300,000 miles of power lines and it is overly reliant on imported fossil fuels. Therefore, this power system is with big concerns in pollution and energy security. In addition, it is not reliable as evidenced by a widespread blackout in 2003. Furthermore, current power system makes it difficult to bring renewable energy sources to enhance energy security and decrease emission [1].

Category	Deployment Period (2009 to 2012)		Steady State Period (2013 to 2018)		Comments
	Nationwide	CT & NY	Nationwide	CT & NY	
Direct Utility Smart Grid	48,300	3,654	5,800	439	Direct utility jobs created by smart grid
Transitioned Utility Jobs	-11,400	-863	-32,000	-2,422	Utility positions (e.g., meter reading) transitioned to other roles
Contractors	19,000	1,438	2,000	151	External installation and service providers
Direct Utility Suppliers	117,700	8,908	90,000	6,813	Smart grid equipment suppliers (e.g., metering)
Indirect Utility Supply Chain	79,300	6,003	22,500	1,703	Suppliers to Direct Utility Suppliers
New Utility/ESCO Jobs	25,700	1,945	51,400	3,890	New jobs from new smart grid business models
Total Jobs Created	278,600	21,090	139,700	10,575	Total new jobs at end of each period

Table 1 Total smart grid jobs created and transitioned in nationwide, Connecticut, and New York¹

¹ The calculation is based on the KEMA's perspectives with the assumption that the number of the jobs is proportional to the population, where U.S. 304 million, CT 3.5 million, and NY 19.5 million

In order to improve energy reliability, security, and efficiency, smart grid power system attracts more and more attention. The research and implementation of this power system are convinced to contribute to job creation, preservation and economic recovery. Moreover, this system can incorporate distributed energy storage and distributed renewable energy resources, including solar, wind, biomass, and tidal energy. This will reduce the dependence on imported oil and gas and improve energy security. Therefore, it also Lower emissions of greenhouse gases. It is estimated that up to 280,000 nationwide jobs can be created directly from the deployment of smart grid technologies (see table 1). Over 150,000 of these jobs would be created by the end of 2009, and nearly 140,000 newly created high-value positions would become permanent after a smart grid deployment [2]. Thus, achievement of a national smart grid requires extensive workforce training in the power generation from traditional and renewable energy resources, electricity transmission and distribution, and cyber security, etc.

Although there are many universities offering different courses related to power system, the course on SG power system is still not available. The most possible reason is that SG is still under development and no SG power system was already deployed. Therefore, the topics on SG are not well defined and there is no textbook available for teaching.

University of Bridgeport (UB) is located in Bridgeport, CT. In the School of Engineering, there are Electrical Engineering Department, Computer Science and Engineering Department, Mechanical Engineering Department, and Technology Management Department. Courses related to smart grid system have been provided for several years and these courses include Electricity Transmission and Distribution, Power Electronics, Alternative Energy Technology, Solar Energy, Fuel Cells, Information Security, and Project Management. In addition, a new Master of Science program in Sustainable Energy Engineering and a new Renewable Energy Research Lab are being proposed and established.

In this paper, we summarize the essential topics in SG and mingle the SG knowledge with some existing courses in energy. We develop a model to simulate SG and this simulation enhances the teaching.

2. The education in smart grid technology

A smart grid has following characteristics:

- Be able to integrate renewable energy resources and energy storage, the two-way transmission allows customers to interconnect renewable energy generation and storage. This will lower peak demand and emissions of greenhouse gases.
- Allow dynamic price, the electricity price is dynamic and customers are encouraged to manage their energy use and reduce their energy costs².
- Be self-healing, monitors and controllers will respond to system problems to mitigate power outages and power quality problems.
- Be more secure from physical and cyber threats, new technology especially in cyber security will enhance the system security.

These characteristics are related to the four main SG components, distributed renewable energy resources, distributed energy storage, transmission and distribution infrastructure, and cyber security.

² Report of the Smart Grid Working Group, Energy Future Coalition

2.1 Distributed renewable energy resources

Renewable energy, such as solar, biomass, and wind, can be utilized and solar panels, small wind turbines, and fuel cells are emerging. The advanced transmission, communication, and control systems make it possible to operate distributed generator networks in coordination with the grid. This eliminates the need for costly peaking infrastructure and insures against blackouts. Smart meter and control system can ship surplus renewable generation from the customers to the grid and credit these customers.

2.2 Distributed energy storage

The energy storage devices include conventional lead-acid batteries, superconducting Magnetic Energy Storage units, flywheels, and electrolyzer with fuel cell. These energy storage devices can be integrated in a smart grid for the following reasons:

- o Stabilize power flows and provide grid shock absorbers.
- o Balance power generation and demand for intermittent renewable resources.
- o Improve the feasibility of microgrids (islanding) or transmission and distribution capability to improve reliability in rural areas.
- o Improve security to emergency response infrastructure and ensure availability of emergency backup power for consumers
- o Facilitate peak load management of residential complexes, businesses, and the grid
- o Make better use of existing grid assets with the energy stored during non-peak generation periods.

2.3 Transmission and distribution (T&D) infrastructure

The transmission includes substation automation, dynamic limits, relay coordination, and the associated sensing, communication, and coordinated action. Distribution includes distribution automation (such as feeder-load balancing, capacitor switching, and restoration), enhanced customer participation in demand response, outage management systems, voltage regulation, VAR (Volt Ampere Reactive) control, geographic information systems, data management, and mobile workforce management, and improved power quality to meet the range of customer needs. For T&D in smart system, the following issues will be focused on:

- o T&D system reliability: duration and frequency of power outages
- o Advanced meters: percentage of total demand served by advanced metered customers
- o Advanced system measurement: percentage of substations possessing advanced measurement technology
- o Generation and T&D efficiencies: energy conversion efficiency of electricity generation, and electricity T&D efficiency
- o Dynamic line ratings: percentage miles of transmission circuits being operated under dynamic line ratings
- o Power quality: percentage of customer complaints related to power quality issues (e.g., flicker), excluding outages

2.4 Cyber Security

The smart grid is supported by IT. The automatic control of the system is based on the communication among the subsystems and information from sensors and meters. Therefore, the cyber security risks always exist there and how these risks can be mitigated is a big challenge.

3. Course project on smart grid

It is difficult to do experiment on smart grid in our teaching since a lots of components are needed. However, a model of smart grid can be developed to illustrate the working principle of this new power system and the modeling is also expected to attract students' interest. In this paper, a SG system consists of several subsystems, called micro- grids (MGs). Each MG consists of loads, renewable energy resources, and energy storage sites. In all MGs, the loads have different priorities, and the electricity at central dispatch has a dynamic price. There is one resource manager for each MG, and these resource managers control electricity transmission between the MGs through central dispatch. Under certain circumstances, intentional “islanding” of one MG provides local reliability, stability, and security. This does not change or disrupt the integrity of the transmission grid as a whole [3]. Furthermore, an overall performance metric evaluates an individual MG with consideration of its cost, environmental effect, and load satisfaction.

3.1 Simulation Model

A SG consists of multiple MGs and one power plant. Figure 1 shows a SG structure. In each MG, there are several components including energy generators, energy storage sites, and loads. In addition, there is one resource manager for each MG, and this manager consists of static switches, a microprocessor, and network connections [3,4]. Most of the MG components are implemented as threads in the simulation. The energy generator, energy storage, and loads periodically update the manager about their status.

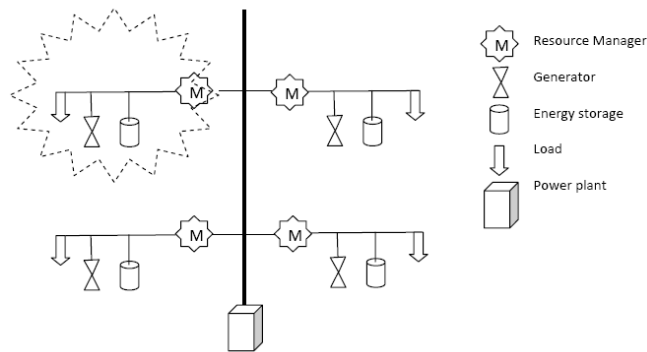


Fig. 1. The structure of a smart grid with four micro- grids

For the economic return on the investment of an individual MG, a performance metric for each MG is proposed. An overall performance index of each MG can be calculated as:

$$Q = w_1 F + w_2 E + w_3 S \quad (1)$$

F is a cost index of electricity, E is an environmental effect index due to atmospheric emissions, and S is a satisfaction index of the power delivered to the loads. Q, F, E, and S are all between 0 and 1. w_i ($i=1, 2, 3$) are weighting factors and $\sum w_i = 1$. The ultimate objective for each MG is to maximize its overall performance index. Although this performance index is introduced for one MG, it can be applied for an entire SG under certain circumstances. In this simulation, w_1 , w_2 , w_3 are set as 0.5, 0.3, and 0.2, respectively.

3.2 Results and discussion

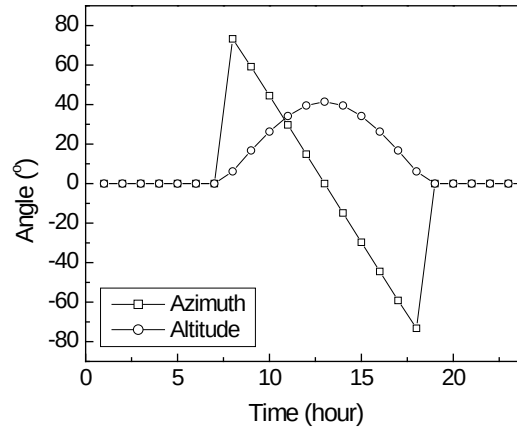
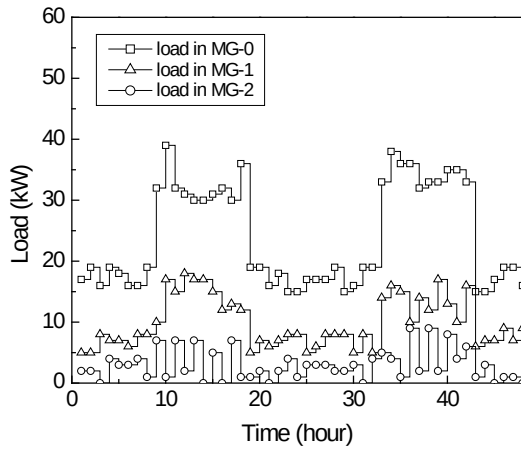


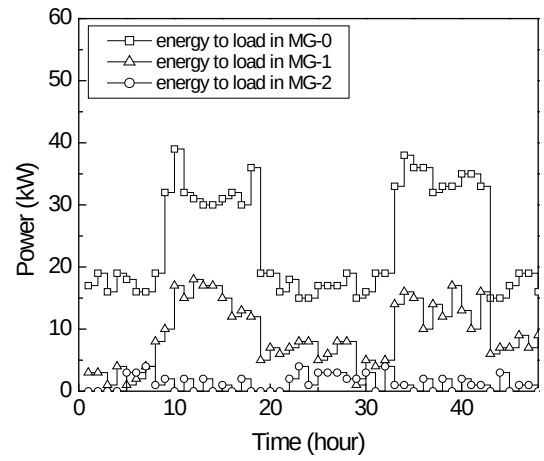
Fig. 2. Solar position at different time

For this simulation, the SG system is assumed to be located at Bridgeport, Connecticut, U.S. (longitude 73, latitude 41). The solar position is estimated via reference [5]. Figure 2 shows the solar azimuth and altitude on February 26, 2010, and this result is verified from reference [6]. The sun rises at 6 o'clock and sets at 17 o'clock. The solar position will be used to calculate the power generated through the solar panels in the following cases.

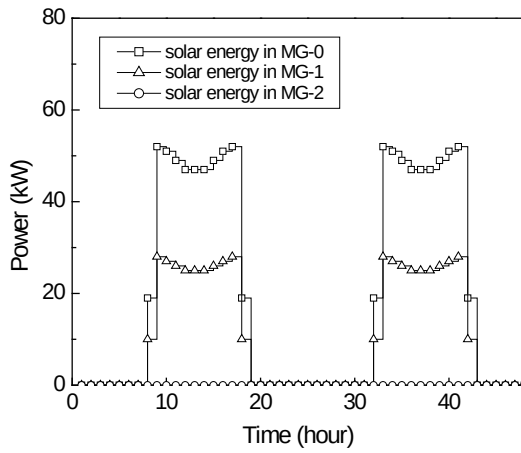
One SG consists of multiple MGs, and there are generators, loads, and energy storage sites in each MG. The loads have different priorities and the price of electricity on the SG is dynamic. Power is preferentially given to meet the load with a high priority, with no consideration of the price of the electricity. For the load with low priority, the power from the SG is only transmitted when its price is low.



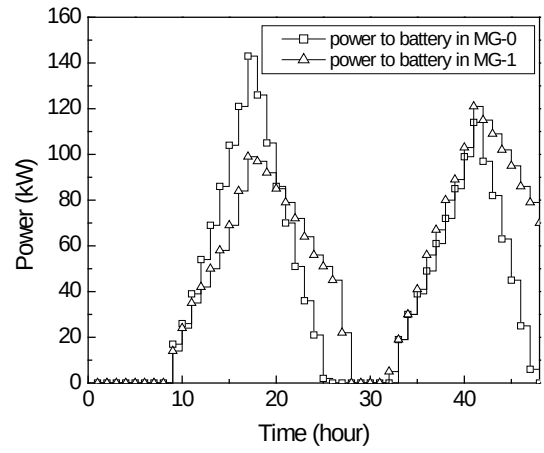
(a)



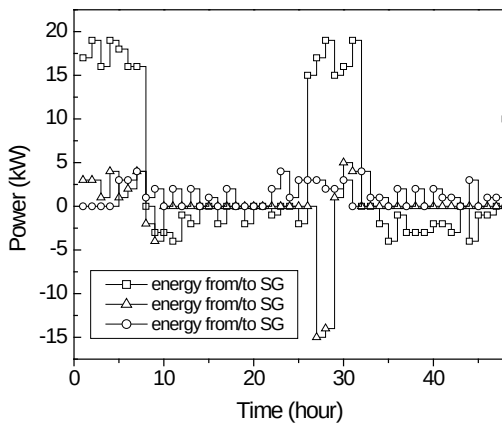
(d)



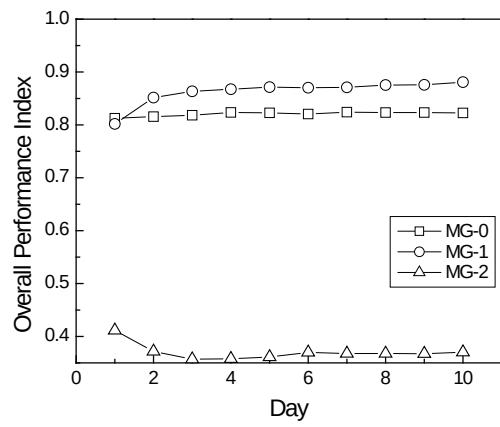
(b)



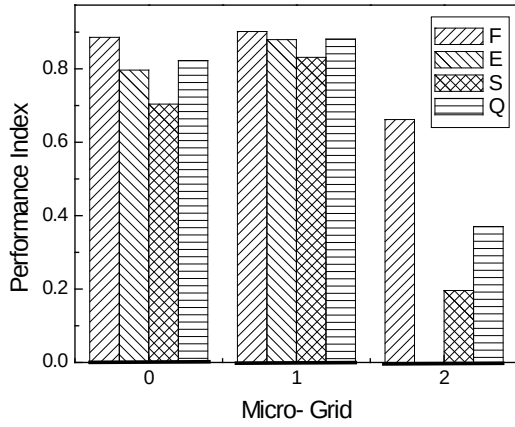
(e)



(c)



(f)



(g)

Fig. 3. A SG system with three MGs: (a) loads, (b) energy from solar panel, (c) energy from or to SG, (d) energy to the loads, (e) power to the batteries, (f) the overall performance, and (g) the performance indexes.

Figure 3 shows the results from a smart grid including one power plant and three MGs, as MG-0, MG-1, and MG-2. The loads in these MGs are shown in Figure 3 (a), where load (MG-0) > load (MG-1) > load (MG-2). 30% of these loads are with a high priority, 30% with a normal priority, and the rest with a low priority. There are solar panels in MG-0 (150 m²) and MG-1 (80 m²) but none in MG-2. Figure 3 (b) shows the power generated through these panels in the first two days. Figure 3 (c) shows the power transmitted in two ways between MGs and the SG central dispatch. Much energy is transmitted from MG-1 to the smart grid due to the area of the solar panel and the load. The real energy used by the loads is shown in Figure 3 (d). In the day time, energy is only guaranteed to support the loads with high priority, assuming that there is not sufficient energy for all of the loads. Figure 3 (e) shows the accumulated power to the batteries in MG-0 and MG-1. For the MGs with solar panels, the power to the batteries increases at 9 O'clock and decreases at 16 O'clock. In the first 24 hours, neither MG-0 nor MG-1 can be stand-alone systems. But from the second day, MG-1 can be independent of any external energy supplier. Figure 3 (f) shows the overall performance indices of the three MGs in the first 10 days. The index increases slowly in MG-0 and MG-1 but decreases in MG-2. Figure 3 (g) shows the indices of price, emission, and satisfaction based on equations (1-4). The price index of MG-0, 0.92, is the highest since it sells energy in the day time and purchases much of its energy at night. This is also the reason for the lower emission index in MG-0, 0.78, vs. MG-1, 0.84. For MG-2, the emission index is zero and the price index is the lowest, 0.61, since all of its electricity is from the SG central dispatch. The satisfaction index in MG-1 is the highest due to its big solar panel and low load. In these three MGs, the overall performance index of MG-1 is the highest.

4. Conclusions

In this paper, a model of a smart grid system with multiple micro-grids is constructed, and this smart grid integrates the solar energy generated and stored. The price of electricity from the smart grid is dynamic, and the loads on the micro-grids each have different priorities. A

performance metric is proposed to comprehensively evaluate the performance of the micro-grids. Through simulation, the overall performance index of a micro- grid with a high renewable energy /load ratio is the highest even though the average electricity cost is not the lowest. The performance of a micro- grid without a renewable energy generator is the worst in terms of price of electricity, emissions, and satisfaction.

In the future, more scenarios will be developed using micro- grids. Better performance algorithms will be developed to predict the demand and priorities, and the capacity of energy storage will be optimized. Moreover, the smart grid system will be dynamic, i.e. micro- grids can join and be isolated from the smart grid over time, for reasons of security and stability.

References

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