### AC 2011-2689: SMART GRID DEVELOPMENT IN ELECTRICAL DIS-TRIBUTION NETWORK

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# **Smart Grid development of Electrical Distribution Network**

### Abstract

This paper will focus on smart grid project design and implementation. The project was developed by students and demonstrates new ideas and teamwork. This project was successfully completed and has been developed, implemented and assessed. Topics covered are: how to build a smart gird by utilizing computer application software tools, design, simulation, and diagnoses of electrical distribution systems. All the real world components in electrical distribution network such as residential, commercial and industrial building are modeled in this project.

### Background

The purpose of this project<sup>1</sup> is to design and implement a small scale electric power network by a team of seven students, supervised by a faculty member. The students' background is in electrical engineering with emphasis in electric power system. The students conducted a study in the field of Smart Grid technologies for history and background information. This work led to designing and implementing a small model of a smart gird power distribution network. The power grid represents the real world aspirations of both government and private industry geared toward building a more reliable, responsive, and overall efficient network of residential, industrial and commercial buildings.

Since the concept of a smart grid is very vague, students chose to implement a time tested and proven aspect of such technology known as smart meters. The smart meter is a wireless device connected to every house, industrial and commercial buildings to provide essential feedback in real time to the power companies. This feedback could be in the form of a fault occurring at that said location, or illegal energy usage. This feedback in real time is very useful to the power companies, given the fact that most rely on feedback via a phone call from the consumer before they know whether or not there is a fault<sup>2</sup> in the system.

Another purpose of implementing the grid was to simulate metering technology at the residential, industrial and commercial level. These meters would send data to a computer which is a simulated control room in order to read where certain faults occur in the system. In turn one could control which areas of the grid would be supplying the power. This represents a simulation of the power company's ability to read and send vital information throughout the grid, thus improving the responsiveness and reliability of the network. Figure 1 illustrates the completed model after it was built and during testing.

The lifecycle of this project was implemented in three different phases and started in September of 2009 and it was completed in May of 2010. Planning and analysis was completed in phase I, design and implementation in phase II, and documentation and students' assessment in phase III.



Figure 1. A model of smart grid in electrical distribution system

# Phase I: Planning and Analysis

Initially, each team member worked on individual research on the concepts of smart grid its purpose. Later on, a decision was made as to what the team wanted to demonstrate with the project. The decision was made to show specifically how smart meters would work and help in fault detection as well as saving money by removing the need for meter readers to read the power meters every month.

A project leader was elected by the team members to coordinate the team work. Meetings were then set up by the project leader, to brainstorm on how the actual implementation was going to be planned. Microsoft Project software was very instrumental to organize the work of the team. Tasks were assigned with specific due dates to keep the project on schedule and under budget.

# Requirements

Since this project was spread over three quarters, students had many deadlines and task that had to be met in order to have a successful project. There were three phases to this project, research, background study and planning during the 1<sup>st</sup> quarter, design and building during the 2<sup>nd</sup> quarter and the final stage of testing and troubleshooting during the 3<sup>rd</sup> quarter along with final oral presentation, simulation documentation and assessment of the project. The students made documents and recorded each steps of the project down to each task and timeline by using Microsoft Project software. The project advisor coordinated the project steps and students were required to present a weekly progress report. This step insured that the project was moving smooth and on the track.

The group was divided into two teams, one in software teams which consisted of two members and a hardware team which consisted of other five group members. The software team was in charge of all the coding and GUI implementation so the actual grid can communicate back and forth with the computer. The hardware team was in charge of the physical grid which consisted of the circuit that was built using logic chips such as MUXs<sup>3</sup>, and Flip-Flops<sup>3</sup>, wiring, creating a map on the grid with houses, roads, school, power stations, sub-stations, transmission lines, and distributions lines. The commercial site consists of shopping area, factories, stadium, school and so forth. In final stages of the project, testing, debugging and troubleshooting was performed in order to assure that hardware components and related software can communicate back and forth in a proper sequence. Much of the requirements had the made along the way since this was very new to all students.

# Phase II: Design and Implementation

The design started immediately after the clear definition of the project requirement and purpose. To lower the cost and improve the safety, the design would be a DC (Direct Current) representation of an AC (Alternate Current) system. The system was designed by drawing out the model of a city and the specific buildings to exist in that city. The design was based on what took place in the planning stage which defined how the city and buildings will receive their power and the power.



Figure 2. The process of building a smart grid

The next challenge in the design process was solving the problem of switches and smart meters. Figure 2 shows the design of the smart meters and placement of LEDs (Light Emitting Diode). The LEDs will represent whether a particular house, building or transformer has power on or off. If for any reason an LED was not lit, then that particular item does not have power. The faults were determined by voltages because even if the building wasn't drawing power, then there still would be a voltage on the line. This voltage was then sent to a 64 to 1 multiplexor which was then sent to the microcontroller to determine faults. To turn the power of buildings "on" and "off" a common NPN<sup>4</sup> transistor (2n2222) and the base current was provided by a flip flop integrated circuit. Flip flops were used due to I/O's limitations of the PIC<sup>5</sup>. Figure 3 was duplicated for every transformer, with the only difference being the number of buildings being fed from the transformer which is the first LED after the 12V source.



Figure 3. Circuit diagram for buildings

#### Implementation

A Smart Grid system includes a power meter which enables the communication systems to update the utility about its condition and the electronics to control the meter. The old electromechanical meters that were used are becoming obsolete since they cannot support the features that the utilities desire to have such as monitoring and controlling power supplied to its customers. Utilities wishes to monitor power consumption so that they can accurately predict how much power will be used during peak and down times. This information is helpful in producing sufficient energy and better efficiency in power waste. It can also help to pinpoint locations of power outages leading to a quicker recovery time.

Challenges in implementation of the system are based on a couple of issues. First is the cost. It could cost upwards of \$1000 for each smart meter, depending on features to be installed for each

house or business. The costs can add up quickly, and the utilities don't see any immediate savings or incentive to deploy the smart grid in a very near future.

The system designed in this project is using smart meters with a simulated wireless connection to the central servers at the utilities. The meters would send a signal to the central computer to update its status, power consumption, and other things. It can be designed in a way that it will have a battery backup for when the power is interrupted, or have the central computer assume it is off when it doesn't send a signal at the regular time intervals. Obviously the latter option would be the most cost effective and would use less power to run. But having power to the smart meter could also be beneficial because diagnostics could be run to determine if the power went out or if the meter is having its own internal hardware problems.

A wireless signal was simulated for this project, but in real world application one can use either wireless, normal phone lines, or communications over power line. Most utilities already have communications systems set up through their power lines and using this method would be most cost effective. Having wireless, on the other hand, frees up usage of the power lines reducing their stress and prolonging the cables life. Companies are developing and testing their own systems using one of those options. In any case, it is based on hardware availability and cost effectiveness. Figure 4 illustrates communication with the smart grid.



Figure 4. Communication with the smart grid

# Phase III: Documentation and Students' Assessment

In phase III of the project, the students provided a detail documentation of the project which includes cost analysis and different phases of the design. An electronic copy of this documentation and demo presentation was produced in a DVD.

The following assessment and lessons learned was observed during the life cycle of the project:

- 1) When the main board that was used in the final project was constructed, the problems of wiring of all of the integrated circuit chips and the PIC chip appeared. The project used multiple prototype board in order to wire the entire circuit. It was concluded that wiring over 500 individual components onto a small confined breadboard space is not easy, and it is almost impossible to be able to connect all of the components without error. This method of wiring is not recommended for future explorations of any project. Instead one should look into the possibility of getting a printed circuit board made. With secure connections available on a printed circuit board, the number of junctions where something can go wrong is greatly decreased. By using a printed circuit board the reliability of the circuit can be greatly increased and can ensure that the possibility of a connection error made is kept to a minimum.
- 2) The implementation of a graphical user interface (GUI) was a great asset. By having the GUI up and running one could efficiently identify if there were any problems that existed on the project board. Even though by identifying where there was an error occurring, sometimes it was not possible to fix all of the problems that occurred in the wiring, resulting to incompletion of the control feature that was initially planned.
- 3) The jumper system implemented into the board allowed audience members to interact with the smart grid by being able to physically create faults or changes to the grid itself. This helps to demonstrate some principles on how it works and what sort of benefits a smart grid can bring. The drawback of this implementation is the way the wires were attached to the jumpers. The back of the jumper is exposed so the wire in the jumper that is part of the same unit can touch each other and create a short circuit. A short circuit will not allow the LED connected to it to operate properly. It is recommended that using better insulation or common connectors instead of jumpers would be more ideal for this kind of application as they would provide better separation of the different wires being connected.
- 4) There was some minor problem with the team work due to time conflict of the team members. Because of this, the group resorted to the waterfall method of development. This allowed everything to get finished independently but instead did not allow for every component to meet the concrete time frame.
- 5) At the end, the project was completed successfully and the functionality of being able to sense the status of the elements such as houses, building and transformers was accomplished. However, the other planned task of being able to control elements on the grid such as remotely cutting power to a house was not fully functional because there were some errors in the wiring which causes multiple houses to be control other than the intended one.

#### Assessment of the students' team work and learning

The following evaluation form was distributed to each student at each phase of the project to monitor the quality of their progress and communications. The students will fill out the surveys

for each members of their team along with some useful comments to help at the beginning of the term and revisit the form and fill out surveys at the end of the term. Below is an average score for one the team members.

Evaluator Name		
Team	Smart Grid	
Date	May 2010	
Person Being		
Evaluated		
Criteria	Rating	<b>Comments (required for each person)</b>
	5= Excellent	
	1= Poor	
Attendance	5	He attended all the meetings
Resourcefulness	4.5	He was very helpful
Quality of Results	4	Most of the time we were able to use his results
Support of &	3.5	He mainly focused on his area of expertise
Assistance to Team		
Quality of	4	He communicated well with the team
Communication		
TOTAL	21	

# **Future Recommendations**

Certain ideas in the future development of the smart grid projects are:

- Design and implementation of a smart metering device
- Wireless communication with the grid
- Cyber security defense
- Topology view of the grid from the control center
- PCB of the circuit design to add simplicity to the main board

Implementing any of these ideas would lead to a step closer to the realization of what a true smart grid would look which is a step toward a reliable, efficient, and responsive power distribution system.

# Conclusion

The Smart Grid Project has some feasibility for parts of it being implemented in the future, most likely because it is only the first prototype of the system. Each utility has its own way of implementing its own smart grid. Implementation would be faster and more cost effective if

utilities decided on a standard to adopt for the smart grid system. Also, installing smart meters has a high initial cost making the utilities wary of adopting it wholeheartedly without testing its feasibility and cost over an extended period of time.

Every project is unique and has its own sets of requirements. Initially the students had no idea of what a Smart Grid looks like and they had no idea on how to go about doing things because this it is a new area of study for most with a lot of unknown ingredients. One can actually say that the final product will be somewhat unique what a smart power grid might look like in the future.

Overall, the smart grid project was a success because the project has demonstrated the principles of a smart grid. The project falls short where the functionality of the system has not been fully realized due to complications that arose during the construction of the project. The theory behind this project is relatively simple; the challenges arise from implementing the ideas on a large scale. During small scale testing, the hardware circuit as well as software programs performed successfully. These tests conducted as expected and the design worked flawlessly.

### **Bibliography**

- 1. S. Monemi, B. Watkins, C. Bolton, A. Manimbo, Y.C. Tsang, N. Patel, J. Gurr, J. Huynh, "Smart Grid Design and Implementation" Senior Project Report, Cal Poly Pomona, June 2010.
- 2. S. Monemi, "An outage Restoration Management System for Power Distribution Networks" ESRI Electric and Gas user conference, Fall 1999, Phoenix, AZ.
- 3. Brown and Vranesic, "Fundamentals of Digital Logic with Verilog Design", 2003, McGraw Hill.
- 4. R.C. Jaeger and T.N. Blalock, "Microelectronic Circuit Design", 4<sup>th</sup> Ed., McGraw Hill, N. Y. 2008.
- 5. Mazidi, McKinlay, and Causey, "PIC Microcontroller and Embedded systems using assembly and C for PIC18", Pearson, Prentice Hall, 2008.