Boston University
Electrical & Computer Engineering
EC463 Capstone Senior Design Project

Problem Definition and Requirements Review

Smart Grid Test Facility

Submitted to:

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Customer Sign-Off ______________________________________

Smart Grid Test Facility

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Project Summary

The objective of this project is to design and construct a smart grid test bed for classroom demonstrations and experiments in undergraduate and graduate settings. Students in power and electric energy courses can study their designed grid elements using this test bed. Smart grid technologies refer to devices that are created to make the electrical grid more efficient, economical, and reliable. Teaching students about the electrical grid will encourage pursuit of new challenges associated with the aging grid infrastructure; the more that engineers focus on updating the electrical grid, the more improvements in smart grid technology and clean energy generation that will arise. This test bed will include a collection of fixed generators, variable loads, a transmission network, and sensors feeding into a visual display. Ultimately, this project will help students learn about the electricity grid and how it reacts to various arrangements of generators, loads, and wiring networks.

1 Need for this Project

Our project is to provide a test bench that can act as a small, low-voltage surrogate for the United States Power Grid with the ability to connect small versions of renewable resources and perform key measurements. It will then be used as an academic tool for various topics related to the general theory and methods behind power engineering, renewable energy sources, and electrical infrastructure. In addition, it will serve as a test bench for the development of smart grid technologies.

Modern American society heavily relies on the functionality of electrical infrastructure with the average home consuming about 900 kilowatt-hours each month. From essential systems such as HVAC and water pumps to discrete devices such as computers, medical imaging systems, cell phones and almost all devices we regularly interact with receive electrical power from the United States Power Grid. Unfortunately, current methods of using natural resources, such as gas or coal, are not sustainable in supplying power. However, the invention of renewable energy resources such as wind turbines and solar panels provides sustainable alternatives. The introduction of these sustainable, but highly variable, alternatives has produced the need for a self-correcting grid with an emphasis on efficiency and sustainability. This is self sensing system is the smart grid.

Formally, a smart grid is a modernized electrical grid that uses analog or digital measurements to gather information about the behaviors of the grid and regulate power flow based on those readings. Using a smart grid improves the efficiency, reliability, economy, and sustainability electricity production and distribution. Mastering the theory of smart grid technology is essential to integrating sophisticated renewable energy resources and their requisite control systems into our power infrastructure. It is hoped that with the full implementation of a smart grid, the United States Power Grid will reach higher efficiency and with the integration of renewable energy systems it will become far more sustainable thereby reducing it’s impact on the environment.

2 Objective and Deliverables

The objective of the Power Pooches team is to construct a fully functioning tabletop power grid test facility with sufficient hardware and software suitable to simulate the behavior of the power grid. This test facility will include DC-powered prime movers and incorporate a lumped transmission structure with loadflow data acquisition. These features are required to be modular and the test bed is required to be self-contained. However, the system should be designed so that future contractors working for the customer can implement upgrades to the design and add features such as Smart Grid technology. The primary implementation of this project will be as a teaching tool in BU courses EC583: Power Electronics and EC417: Electric Energy Systems so the system must be operable within a classroom setting and be safe for use by student operators. The deliverables to the customer are itemized as follows:

Hardware:

i. Electric Machines as Prime Movers – The project will include no less than 3 DC motors acting as simulated prime movers (coal, gas, nuclear). These will power interconnected generators providing 12V AC power to the grid. It is important that these prime movers present as synchronous electric machines as this is a large topic in the learning goals of EC417.

ii. Lumped Transmission Line Structure – The transmission line structure of the grid will be designed to mimic the characteristics of the actual power grid on a per unit-length basis. That is, the average transmission line characteristics of the American power grid will be used as a standard for modeling the qualities of the transmission lines present in the final product. Additionally, the structure will be modular so that converging power lines and multi-path power transmission schemes can be modeled. Finally, these lines will have connection points for various load configurations.

iii. Isolatable and Variable Loads – The loads included in the final product will be provided in binary modules so that instructors and students can easily change the load magnitude. Simulated resistive and reactive loads will be provided. No less than one resistive, capacitive, and inductive binary load will be provided; multiples will be provided if costs permit.

iv. Green Input Ports - A major focus of energy technology and education is the rising impact that renewable energy sources can have on the grid. Pursuant with the goal of designing an educational tool, the grid will have input ports designed to receive an unspecified 'Green Input' and report the power flow added to the grid. The expected green inputs are solar, wind, and hydroelectric power. The group will attempt to model these generators if cost and time permit. The customer has indicated that this is ancillary to the primary project objectives.

v. Sensor Feedback Network – The sensor feedback system provided with this project will use current sensors to define the energy flow throughout the circuit. Using an Analog-to-Digital Converter (ADC) connected to a microcontroller, these values will be manipulated and stored to record other circuit parameters such as voltage and power consumption at each node within the circuit. As a primary goal, these values will be used to give feedback through a user interface connected to the microcontroller. If time permits, the next phase in implementing a feedback scheme will be the inclusion of a simulated mimic board that provides real-time updates through sensory indicators such as LEDs or audio feedback.

vi. ADC – The ADC will provide digital information taken from the sensor network to the microcontroller with connections available at relevant nodes within the circuit. Relevant nodes include the outputs of generators, transmission line convergence points, and load connection points.

Software:

i. Programmed Beagle Bone Black – A programmed beagle bone black will be provided along with the project as the on-board control and data processing unit. It will have the capacity to perform ADC readout from the grid as well as being user controllable from a console. Along with acquiring and storing data, it will be possible for the user to retrieve these data and transfer them via USB storage devices.

ii. Full User Interface with Display – The user interface provided with the project will allow the user to observe the current, voltage, and power at points within the grid. The exact display implementation for this deliverable has not been chosen by either our group or the customer, but the likely approach will be to project outputs on an LCD monitor.

3 Visualization

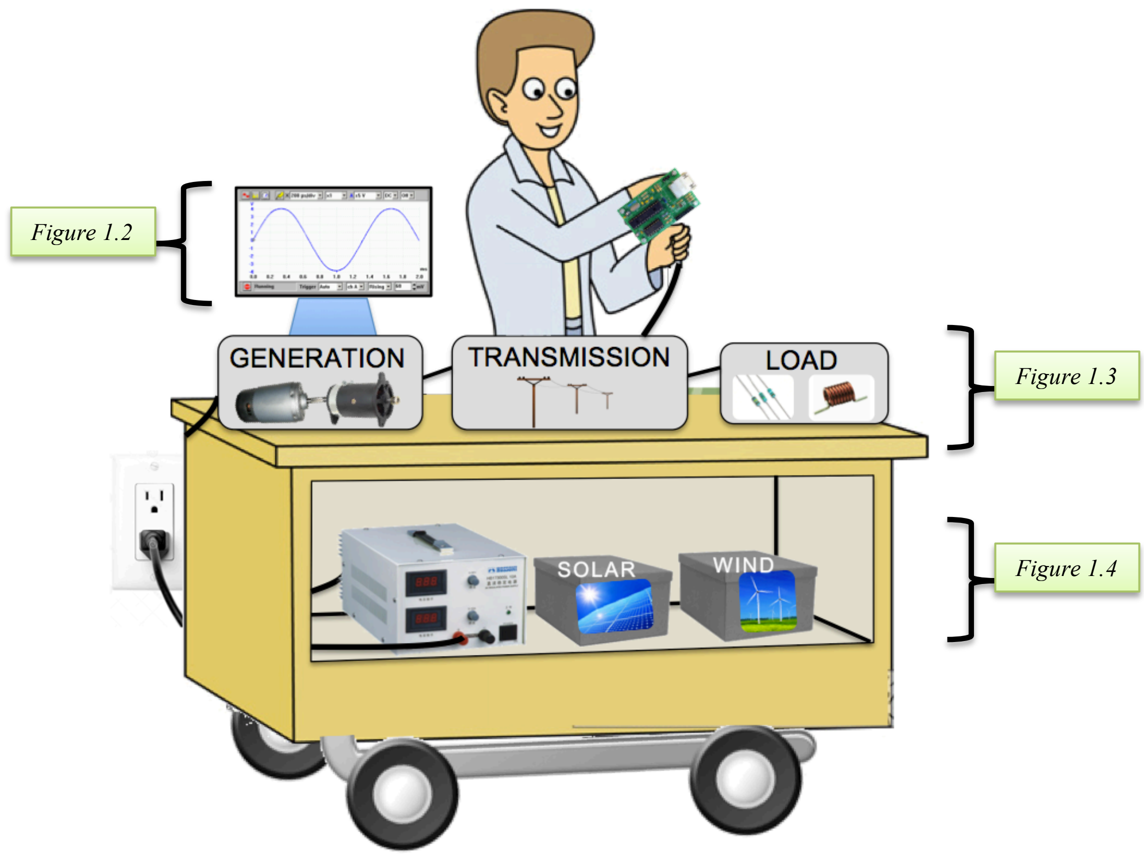


Figure 1.1 This image shows a basic representation of the project's final device system. A student has created a circuit (perhaps a load) that he wishes to test within an electrical grid. He connects his device to the test bed and can observe the grid's response on the monitor.

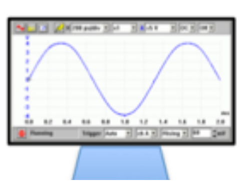


Figure 1.2 A key element of this project is providing students a way to analyze their circuits in the context of the simulated grid network. To do this, the test bed will have an incorporated sensor system that will monitor the current, voltage, and power flows.

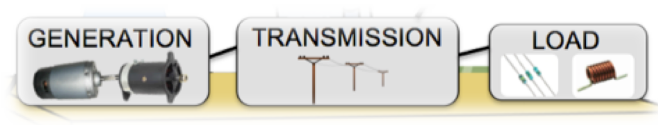


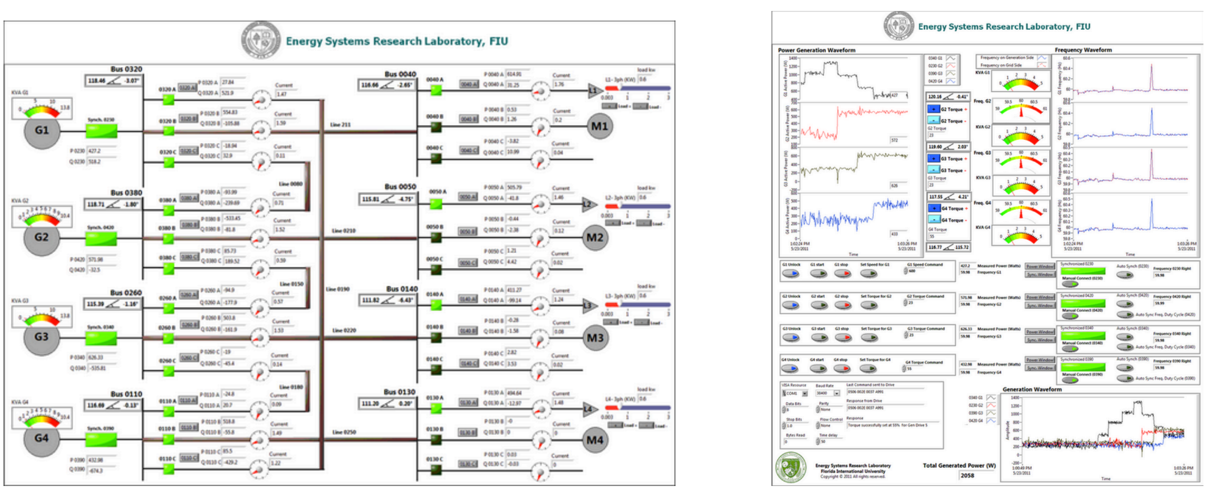
Figure 1.3 The simulated grid is comprised of generators, transmission lines, and loads. The test bed will have a collection of several generators, various transmission lines, and variable resistive and reactive loads. Students will be able to adjust the loads in order to study the way the grid reacts to different levels of demand.

Figure 1.4 A DC power supply (at left) will power the various generators for the grid. While the test bed will have ports for clean energy systems, we also strive to create these simulated clean energy technologies. Because some clean energy systems do not product power in the traditional steam turbine way (such as solar plants which produce DC voltage), additional design considerations will need to be taken in order to create simulated green energy systems. Nonetheless, these types of generators should be available for students to test within the test bed.

4 Competing Technologies

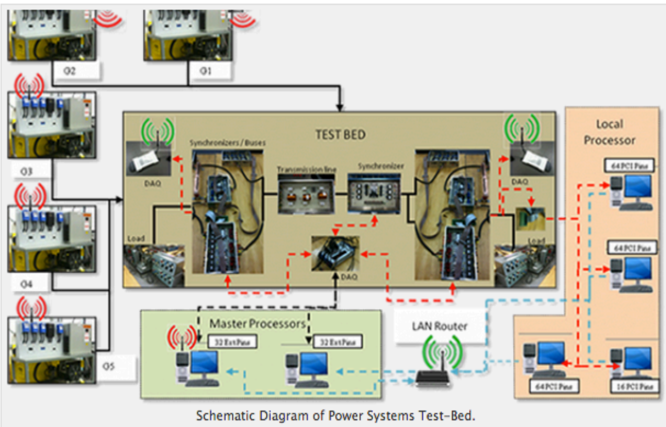
After thorough research, two competing technologies were identified that share a common purpose with our product design. These projects serve a significantly larger scale and employ different methods of addressing the problem of grid simulation, however, they are used for academic purposes, which is why they are considered to be relevant competing technologies.

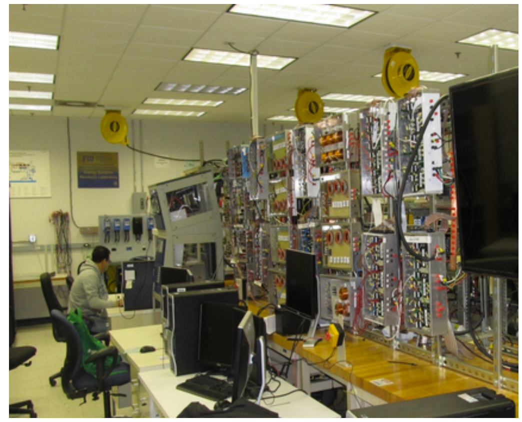
The Energy Systems Research Laboratory of Florida International University houses two configurations that build upon one another. The one that is more closely related to our product is called the *micro power system test bed*. This system uses several power generation stations to model the conventional power plants and allows the operator to monitor and control the power generation. In order to model realistic transmission lines (pi model) the team uses series resistors and reactors with parallel capacitors. The passive and dynamic loads in the system are modeled using constant impedance loads and induction motor loads. The system also uses several different Data Acquisition units (DAQs) to gather voltage and current waveforms from corresponding transducers, data which can be used for calculations of power, frequency, true RMS, etc. The operator controls the system through a GUI on both the generation and load side.



Figures 1.1, 1.2 Florida International University's modeling system for a simulated power grid. The operator can arrange the system using a GUI and observe the grid's reactions.

The second research-based test bed for smart grid technologies builds upon the previously mentioned power grid model. In this setup the students address the "smart" aspect of the grid that revolve around communication of different grid components. The master computer in the laboratory is the central point of the system and gives control commands after retrieving information from different points (using National Instruments DAQs for data gathering and National Instruments LabVIEW for data processing) on the grid through wireless communication. This research bed also focuses heavily on the integration of renewable energies into the grid and has faced many challenges due to the EMC/EMI effects of electronic converters on surrounding equipment. The system has the ability to go up to 75 KW of generation, assuming all five-generation stations, batteries, fuel cells, wind simulator, and PV simulators are connected.





Figures 1.3, 1.4 FIU smart grid test bed schematic and research lab.

The next product we took into consideration was the smart grid test bed constructed at University of Illinois Urbana-Champaign with contributions from many institutions and firms. This system spans all aspects of the grid system including generation, transmission and distribution, everything from meter platforms to home automation. It incorporates many electronic components, unlike the previously mentioned designs. The system makes use of real data from the grid, industry partners, and an advanced metering interface. It is able to provide full power and network simulation, modeling, and optimization/visualization, allowing various research endeavors in the smart grid field, including security.

Figure 1.5 University of Illinois smart grid test bed configuration.

These test systems were developed on a much larger scale with significantly more resources than our endeavor so we believe it is reasonable that our requirements are not perfectly aligned with those listed above. Although we could not find a directly competing “smart” system, we presume that a simpler, smaller-scale version of these systems may show more similarity to our design goals. Moreover, it is worth emphasizing that these systems are neither portable nor small enough for pedagogical use in a classroom which is of primary necessity to the customer.

5 Engineering Requirements

1) There will be at least three source points to install low-voltage alternators that are modeled after high-voltage AC (gas/steam) generators.

2) The "prime movers" (DC motors) used to power the overall system will be energized by a 12V DC power source in order generate mechanical energy with its spinning rotor.

3) The maximum output power of our entire test system will be 1200W at peak loading. This is derived from the product of the constant 12V produced by our power supply and its maximum current full-load output of 100A.

4) The output of each of our single-phase 3600rpm alternators must produce AC sinusoids at a frequency of +/- 5% of 60 Hz.

5) The AC output from our low voltage generator must remain accurate within +/-5% of the nominal designated voltage to maintain a small range of tolerance.

6) There will be three or more transmission lines provided to connect with resistive, capacitive, and inductive loads in an organized grid structure.

7) Consequently, there will be at least three outlets where RLC loads can be attached to the network to simulate end users/residential customers.

8) Each individual transmission line segment will possess inherent RLC characteristics that must be proportional to typical values in the national utility grid. Primarily, each transmission section will share line losses due to implemented measurements based on average transmission line distances (beginning at the power plant) and also series resistance/inductance along with parallel-coupled capacitance.

9) The project will have more than one resistive load and each power resistor will be 255Ω. Resistive loads for our test bed will operate through a binary control system.

10) The voltage-current V-I characteristics measured by our real-time data acquisition system must be calculated and graphed with less than 5% error.

11) The power factor calculated as the quotient of the net system resistance divided by the overall impedance should yield a $\cos\theta$ result with +/-5% accuracy. If we neglect transmission inductance, a purely resistive network shows a unity PF of 1.

6 Appendix A: References

"Real-Time Monitoring, Operation and Control of Laboratory Test-Bed Micro Power System." *Energy Systems Research Laboratory*. Florida International University. Web. 9 Oct. 2014.

"Smart Grid Test Bed." *Energy Systems Research Laboratory*. Florida International University. Web. 8 Oct. 2014.

"Smart Grid Test-bed Research Lab." *Energy Systems Research Laboratory*. Florida International University. Web. 9 Oct. 2014.

Yardley, Tim. "Smart Grid Testbed Overview: The Whirlwind Tour." University of Illinois Urbana-Champaign. Web. 9 Oct. 2014.