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Development of Laboratory Based Smart Micro Grid To Be Used As An Educational Tool

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DEVELOPMENT OF LABORATORY BASED SMART MICRO GRID TO BE USED AS AN EDUCATIONAL TOOL

A Thesis

by

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ABSTRACT

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The increasing trend of the energy industry to move towards a new smart power grid has pushed researchers to address the challenges that this represents. Universities all around the world are also under pressure to better prepare their students to meet the challenges that await them with this new technology and techniques. The work presented on this thesis was motivated by the current need of the electrical engineering curriculum to include new material into their current courses. A laboratory based smart micro grid was created by applying several concepts and techniques currently being adopted by the energy industry to make their distribution systems smarter. A series of experiments were conducted in order to test the functionality of both hardware equipment as well as software implementation. The results indicate that the experimental setup has proven to be adequate to introduce students to new concepts of the smart grid.

DEDICATION

I would like to dedicate this thesis to my family; they have supported me throughout my academic career. To my mom, Martha Luz Morales, for her unrelenting faith in me, for her ability to always see the best in me, even when I could not. To my dad, Jose Luis Sanchez, for teaching from very early on that a real man doesn’t quit at the first sign of trouble, that a man is responsible and must be proud of what he does, whatever it may be. Their teachings have gotten me trough the hardships in my life, both inside and outside of a classroom. Also to my friends who have become a second family to me, they were always there ready to make me smile, especially when I wanted to cry, thank you all, I couldn’t have done it without your friendship, jokes, and your support of my crazy endeavors. Thank you!

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I would like to thank Dr. Jaime Ramos who not only served as my advisor, but also as a mentor and a guide, he pushed me to become a better researcher and a better student, and also to love electricity for what it is.

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I want to extend a very special thank you to Dr. Heinrich Foltz for always making himself available to my crazy questions; he has been a true guide all throughout my undergraduate and graduate career.

Finally, a thanks to my colleagues in the power systems lab, who where always ready to lend a hand to a frustrated student cutting wires.

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CHAPTER I

INTRODUCTION

In recent years the need for a new structure of power distribution has increased dramatically, the utility companies agree that with the rapid growth of urban areas, increase in population, and the geographic diversity of new settlements, comes a new challenge for the power distribution aspect of the energy production, a challenge that the existing power grid is ill equipped to deal with.

The key to making things better is two way data communications along all the elements so that information about the grid's condition can be shared and acted upon; this concept of new power grid has come to be known as the smart grid.

The smart grid however, does not represent a complete recreation of the existing grid, it is more like the next evolutionary step in power distribution, and therefore, the smart grid must be compatible with the existing grid. In other words the smart grid concept represents the improvement over the existing structure in order to make it resilient and address different concerns, such as optimal deployment of resources, generation diversification, among others.

The scope of the smart grid is a complete overhaul of the existing grid, and of new ones to come.

This scope is of global proportions, and consequences; however to tackle such an enormous and policy changing approach would be unwise, instead research and utility companies have turned to a smaller, more manageable alternative, the microgrid.

The microgrids are defined as “interconnected networks of distributed energy systems (loads and resources) that can function whether they are connected to or separate from the electricity grid” [1]. These microgrids can be made to be intelligent and thus represent the basic structure of the smart grid; this approach will allow the integration of these different and versatile smart microgrids in order to make the transition from the existing power grid into a fully realized smart power grid. The objective of this thesis work is to develop a laboratory based smart microgrid to be used as an educational tool.

Chapter II provides the reader, through the literature review, with a better understanding of the problem at hand and a background overview of the topic. Chapter III contains the objectives that were set for this work. Detailed description of the experimental equipment and setup are provided in Chapter IV, followed by the results obtained through experimental methods along with a discussion of said results in Chapter V. Chapter VI is the final chapter, closing with the conclusions of the project

CHAPTER II

LITERATURE REVIEW

The effect that high carbon emissions is having on the environment, rising fuel costs and increase in population are some of the main challenges that the smart grid is confronted with. For the next generation of power grids to become a reality there must be a shift in paradigms, and a partnership between researchers, governments and utility companies to establish the environment into which this new technologies can prosper. Said partnerships exist today with various focuses and scopes of reach. One of these focuses is the usage of the microgrid's ability to operate in islanded manner from the main power grid and to integrate renewable energy sources such as photovoltaic arrays, wind turbine generators, and bio mass boilers, amongst others [3].

Said ability to exist isolated from main power lines becomes extremely valuable in rural and secluded areas, where the cost to extend power lines to cover the energy requirements of a small population area, far surpasses the profit from said area's consumption, as is the case of several remote villages in Alaska [14].

Other initiatives are driven by both government and private efforts to design, test and more importantly, successfully implement new devices that can make the transition for consumers into the smart grid, with the lowest cost possible. Smart meter technology has emerged for this purpose, and some countries such as Canada have huge groups of researchers funded by government and utility company funds to come up with new technology in this area [3]. Also developing countries, such as Singapore have taken a keen interest into this technology with one very important aspect in mind, which is the cost of each individual unit and how it would translate to the end user [12][19]. The use of smart appliances to lower the end user energy consumption has been explored as well [4].

However with so many companies, government and individuals taking an interest into developing their own microgrid, the need for new control schemes is obvious and with such different and varied components that make up the microgrids comes the issue of how to optimize it properly, such that there are less power losses, and less peak demands that could potentially over-tax the current generation facilities [13]. Several researches has been focused in this aspect of the microgrid implementation some propose a more software oriented approach such as the use of multi agents that can communicate through different protocols in order to maintain system performance, and enhance it with self healing and monitoring capabilities which will make them true smart microgrids [2][25]. Others propose that a new hierarchical control is necessary in order to replace the current central one, which is inadequate given the communication capabilities of the smart grid [5][17][20][21] .

With a project so vast, so multi-purposed, so worldwide spread it is easy to understand that it will take several years, if not decades, to achieve the level desired so that all the aspects of the energy industry can be called “smart”. In order to maintain, or better yet, increase the level of progress in this field and with more and more universities adding courses in Renewable Energy, a subject that seems to go hand in hand with the smart grid, it is necessary for the new generation of students to be prepared to meet the challenges that already await them [6][31]. For this purpose some efforts have been taken to take the academic side of the smart micro grid into the universities of the world. Some rely on already existing problems that are presented to students to be solved in a theoretical fashion, then some of said solutions are implemented by the utility companies in charge of the project, such is the case in [14]. Others such as [15] take a more hands on approach to the subject; however it is still focused on the generation point of view of the energy system.

Therefore this thesis work aims at increasing and enhancing the research aimed at the classrooms, by creating this laboratory based smart micro grid, with a focus on the distribution side of the grid, that is, the view of the utility companies who are the medians between generation facilities and end users. With this the students will be better prepared to meet the industry’s demands that await them after graduation.

CHAPTER III

OBJECTIVES

The scope of this thesis work is to create a laboratory based smart micro grid. A focus is given to applications that allow electric companies to monitor and control the end user electric loads, that is, the electricity provided and how it is distributed among the users. The main purpose for the creation of this hardware and software is so that it can function as a tool for student research on the various topics that encompass a smart grid system, such as communication and control systems, and to provide a testing tool for new implementations and schemes that can be developed in the future.

Making use of the equipment available in the laboratory, which is mentioned and described in Chapter IV, and with the LabVIEW software from National Instruments enabling the communication and control of said equipment, the following are the functions that are implemented in this laboratory based micro grid.

Demand Controller

This system allows the software to monitor and control the power demand of an electrical load. It is done by determining which loads are high priority and which ones are low priority. The user can specify a power consumption limit which governs the system. When the power limit is reached or surpassed, the system automatically disconnects a low priority load, when the demand has returned to low levels of power consumption; the system can reconnect the loads automatically.

Voltage monitoring system

This section of the test bed is designed to monitor the voltage levels being measured from the different electrical loads throughout the system. The user can specify a low voltage level value, the software compares the measurements to this value and determines if it has been reached or not, if it has been reached the system sends a visual alarm for the user to take note that the voltage is behaving with irregularities. The alarm specifies which phase is being affected.

Power factor penalty simulation

The purpose of this section is to implement the techniques used by the power companies to penalize business clients when their power factor is below a certain percentage. The equipment used in the laboratory allows for power factor (PF) measurements, using this ability it is determined if the percentage is above or below the previously specified limit. This emulates the procedure from the power companies where based on the highest KWh measurement of the month (the measurements are taken in 15 minutes intervals) is matched to the power factor at that specific moment and it is determined if the user will incur in a penalty or not, this is done for every billing period.

All of the previously described functions are to be used for initial analysis and understanding of the broader picture that is the inception of smart technology into the power distribution grid. This work is meant to open a gateway for further research and development of the different aspects that this new technology possesses.

CHAPTER IV

EXPERIMENTAL SETUP AND PROCEDURE

Laboratory equipment

PM300 three-phase power analyzer

The PM300 is a power analyzer that is capable of single or three phase measurements. It is described as “a versatile bench-top power analyzer, ideal for measurements of watts, volts, amps, power factor, harmonics, distortion and Wh in the design, development and prediction test of 50, 60 and 400Hz three-phase electrical equipment”[27].

This device acts as a “smart meter” in the experimental setup of the test bed. While this device is not the same as the ones used by the electric companies, the measurements it provides and the ability to have two way communication with a computer make it a very versatile and appropriate for this application. The meters are able to take single and three phase measurements, depending of the setup and wiring pattern followed. For the test bed purposes, the 3-phase 4-Wire mode is used; **Figure 1** illustrates the wiring diagram to achieve 3-phase measurements.

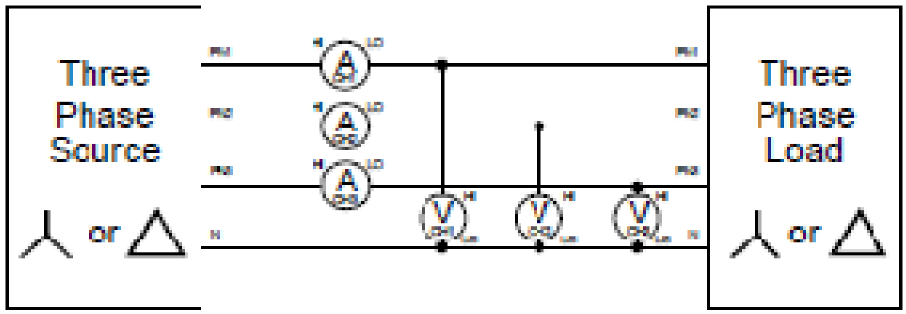


Figure 1: 3-Phase 4-Wire connection for PM 300 Meter

Using Voltech's IEEE 488 communications card, shown in Figure 2, we are able to interface the smart meter with the GPIB IEEE 488.2 Card installed in the main computer. By doing so, we can send requests to the meter for the different measurements, and the meter takes said measurements then transmits them back to the main computer. "The instrumentation bus uses 8 bit parallel data transfer with hardware handshaking on a multi-drop bus. Devices on the bus are assigned a unique address from 2 to 30 and may receive or transmit data using a single bus controller. Although only one controller may be active at any one time, any number of connected controllers may request control of the bus at the same time. Each device receives and transmits data asynchronously using dedicated handshaking lines so that communication occurs at the fastest rate that each instrument can manage."[28]

Figure 2: PM 300 front view and rear view showing IEEE 488.2 Interface card

NIELVIS

"NI ELVIS includes 12 of the most commonly used laboratory instruments including an oscilloscope (scope), digital multimeter (DMM), function generator, variable power supply, dynamic signal analyzer (DSA), bode analyzer, 2- and 3-wire current-voltage analyzer, arbitrary waveform generator, digital reader/writer, and impedance analyzer in a single platform. This compact, yet powerful assortment of instruments translates into cost savings for the lab, both in terms of lab space as well as lower-maintenance costs. In addition, because NI ELVIS instruments are designed using the LabVIEW graphical

system design language, educators can customize the instruments to meet their specific needs."[29]

The readiness of the NI ELVIS to be integrated to the LabVIEW software, and the ability to transmit and receive through 8 digital I/O ports, are the characteristics that have made it suitable to be part of the demand control hardware. The device is shown in **Figure 3**

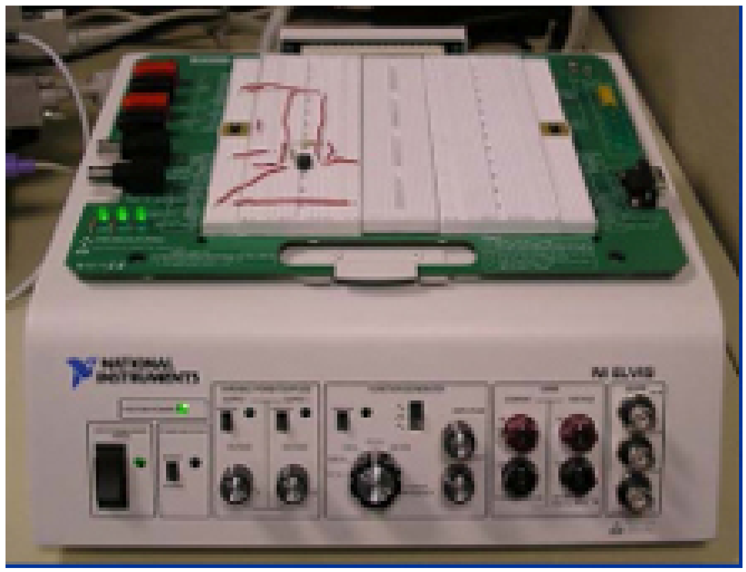


Figure 3: NI ELVIS

Wound Rotor Induction Machine (WRIM)

WRIM has the following specifications: Model WRM-100-3A Wound Rotor Motor**.** The WRM-100-3A is a three-phase, 1/3 HP four pole, wound rotor motor consisting of a stator winding and a rotor winding with slip rings and brushes.

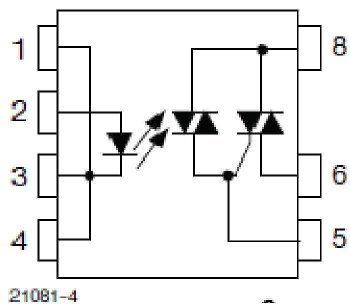
This motor, shown in **Figure 4**, will fulfill the role of 3-phase load for the demand control portion of the experimental set up. It will also be paired with a DC motor in order to function as a generator in the generation monitoring part of the test bed. In its function as a 3-phase load, it is paired with a prony brake that allows the user to increase the torque resistance that the rotor is met with, and thus, increasing the power consumption of the WRIM. This particular trait is used during the testing of the demand control implementation, later described in greater detail this chapter.

Figure 4: Wound Rotor Induction Machine

Power Phototriac (VO2223A)

This device consists of an optically couple phototriac driving a power triac in a DIP-8 package. It provides a 5300 V of input to output isolation. This high isolation capabilities is what makes this component essential to the demand controller system. This provides means for a digital control signal of low DC voltage (5VDC) to be translated into high AC voltage (in this application 120 VAC) and separates the DC input from the

AC output, that is, there is no electrical connection between them, they only interact through the photodiode and power triac. This particular model is capable of maximum voltage output of 600V AC, and output RMS current of 1A, which makes it more than suitable for the demand controller application. **Figure 5** shows the pin layout and internal schematic of the phototriac packaging.



Pin	Function
1	LED cathode
2	LED anode
3	LED cathode
4	LED cathode
5	Triac gate
6	Triac T1
8	Triac T2

Figure 5: Internal schematic and pin layout of Phototriac

Experimental Setup

Demand controlled load response

An important aspect of the smart micro grid is to have self regulation capability. This provides the utility companies with a real time response to high demand peaks. In that sense the demand controlled load portion of the experimental setup is aiming at providing this important feature to the laboratory based micro grid.

The demand control setup consists of two main parts, one is the high priority load represented by the WRIM with a prony brake attachment; and the other is the low priority load represented by three 60W bulbs.

The function of the demand controller is to keep the power demand under a certain specified level. This level is determined by the user and it will reflect the maximum desired demand throughout the micro grid.

Once the system detects that this level has been surpassed, it will react to bring power demand levels below said maximum. It will do so by disconnecting one or more of the low priority loads. The electronic device that provides the connect or disconnect capabilities are the opto-triacs previously mentioned in this chapter, Paired with the NI ELVIS' digital input/output channels, which provide the control signal. A schematic of this system is shown in **Figure 6** and the implementation is depicted in **Figure 7.**

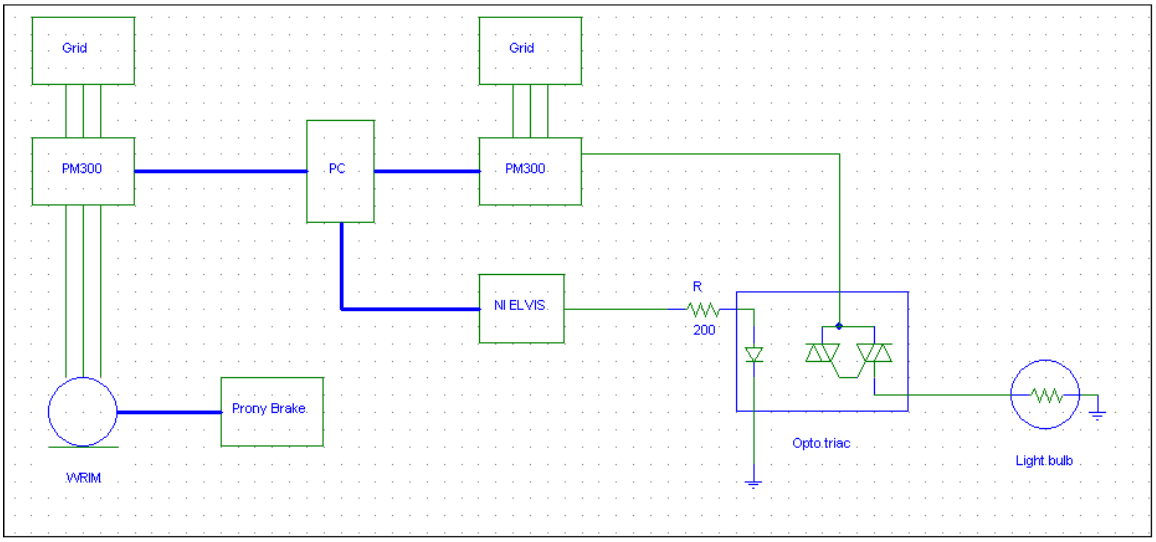


Figure 6: Demand Controller schematic (1-Phase view)

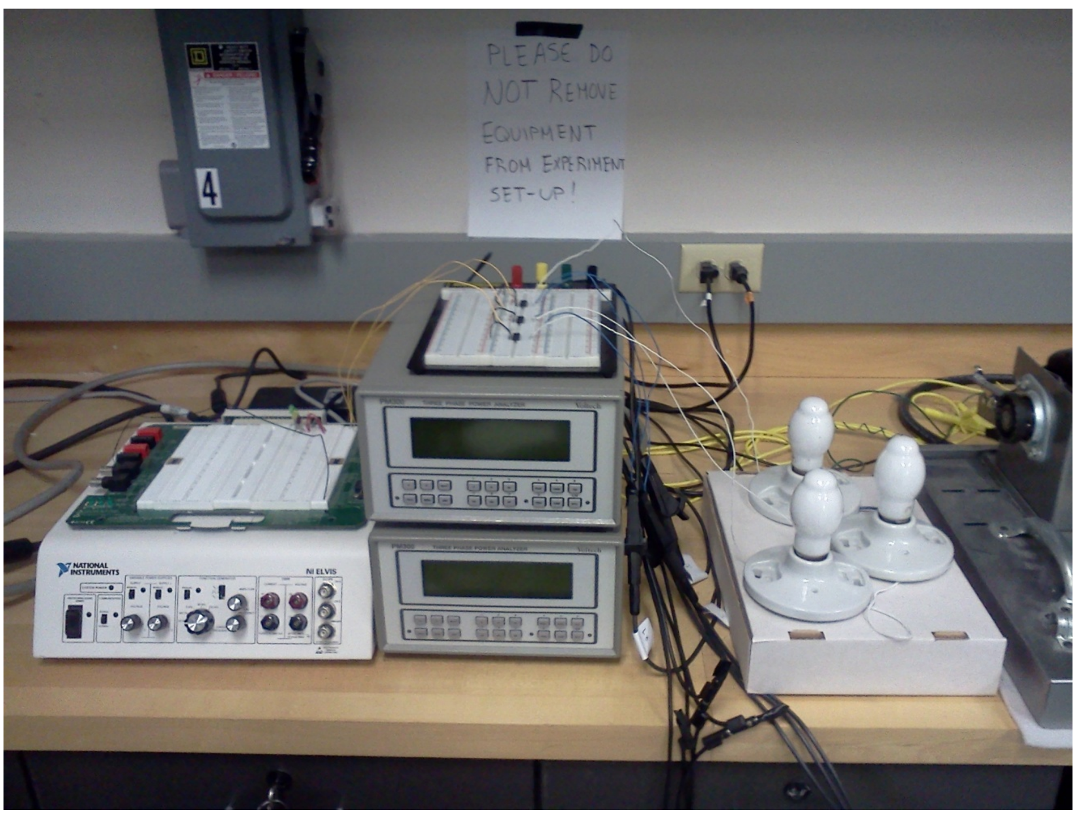


Figure 7: Demand Controller laboratory implementation

When the system detects that the demand levels are well below the specified limit, it will proceed to reconnect the low priority loads. The number of loads reconnected will be determined by how low the demand is, that is, the system will only reconnect the load if adding it will not surpass the limit.

Power Factor billing simulation

The process to calculate the bill's power factor (PF) penalty requires that, the highest power demand measurement over a period of time is determined. The following excerpt is from the Austin Energy Rate Schedule, explaining their method for power factor billing:

"Billing Demand:
The kilowatt demand during the fifteen-minute interval of greatest use during the current billing month as indicated or recorded by metering equipment installed by the City of Austin. When the power factor during the interval of greatest use is less than 85 percent, Billing Demand shall be determined by multiplying the indicated demand by 85 percent and dividing by the lower peak power factor."[29]

The scheme shown in **Figure 8** illustrates how this is achieved. The LabVIEW program obtains measurements of total demand (it is considered total because it is the sum of the power demand of each of the 3-phases) and a Power Factor for each iteration of the timed loop. Initially the values are gathered and they are carried over to the next iteration via a shift register, after the values have been received from the previous iteration, along with the ones from the current iteration, they are entered into a MATLAB code that compares the two values of demand, and determines which one is greater.

Depending on the result the variables are updated and carried into the next iteration to repeat the process.

This logic allows for only the greatest value to be kept in memory, along with its corresponding Power Factor value. Once the process is completed the penalty for power factor can be calculated using the following penalty formula:

$$Penalty = \left(\frac{0.85}{P.F.}\right)(KWh)(Rate)$$

Where "P.F." represents the power factor calculated for the maximum 15 minute KW measurement. The "Rate" variable represents the cost per KW.

The logic that rules the entire Power Factor process is expressed in **Figure 9**

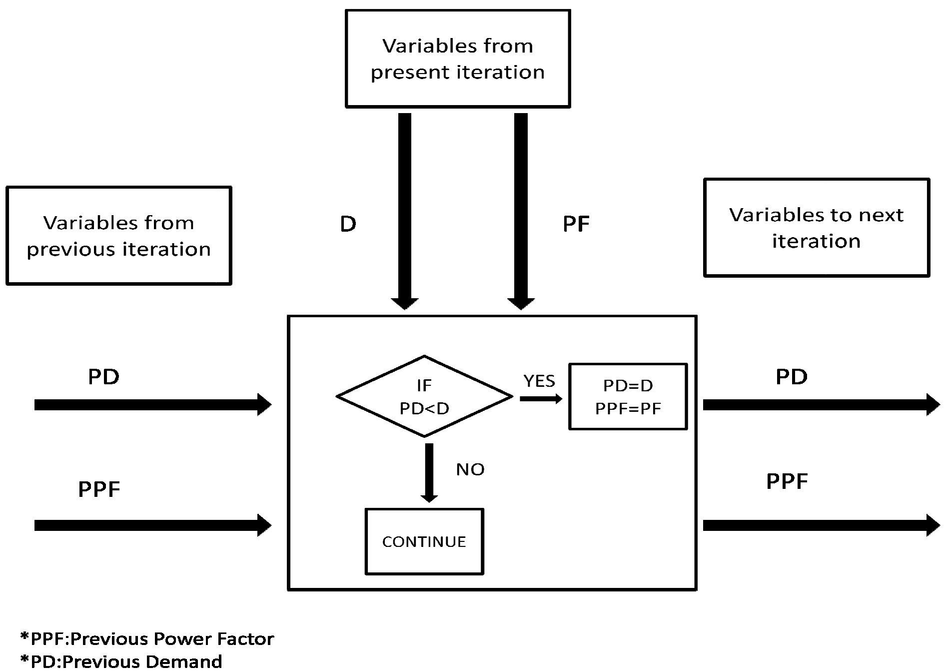


Figure 8: Block Diagram of process to determine maximum power demand measurement

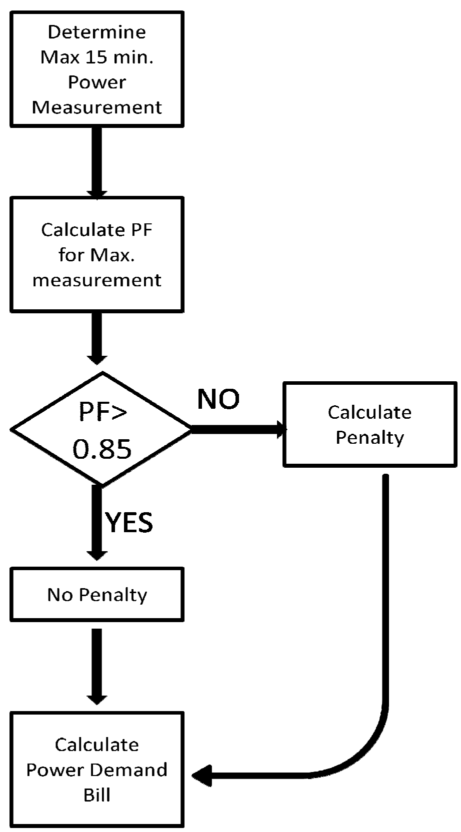


Figure 9: Billing method regarding Power Factor

A variable resistance and variable inductance and capacitance have been connected to the stator of said machine. This will allow the power factor to be raised or lowered so that, a penalty scenario is achieved, as well as the no penalty one. A schematic of this is shown in **Figure 10** and the physical implementation is shown in **Figure 11**. The values that the variable reactive loads can provide are shown in **Table 1** as well as in **Table 2.**

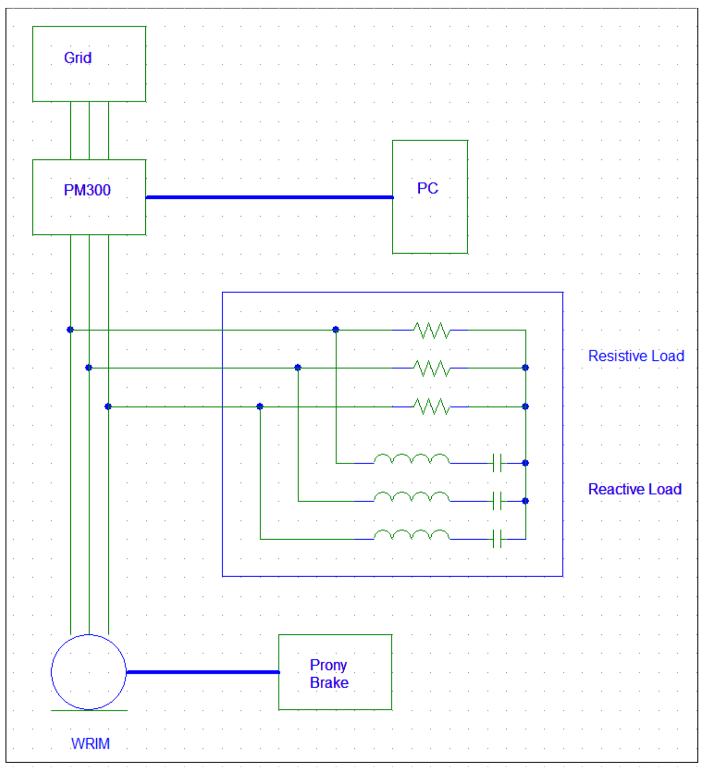


Figure 10: Schematic of WRIM with resistive and reactive loads

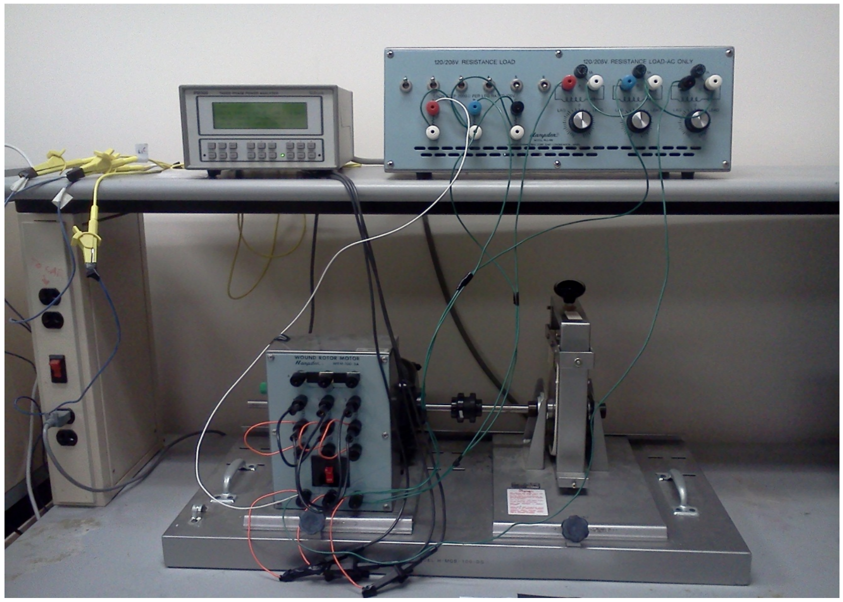


Figure 11: WRIM with variable resistive, inductive and capacitive load

Table 1: Inductance values for variable reactive load

Dial position (counterclockwise)	Inductance (Henry)
0	10.56
-1	9.88
-2	5.16
-3	2.71
-4	1.91
-5	1.43
-6	1.17
-7	0.97
-8	0.85
-9	0.74
-10	0.67
-11	0.57
-12	0.51
-13	0.47
-14	0.43
-15	0.41
-16	0.37
-17	0.35
-18	0.33

Table 2: Capacitance values for variable reactive load

Dial position (clockwise)	Capacitance (μF)
0	0.69
1	1.57
2	3.16
3	5.01
4	6.4
5	8.06
6	9.85
7	11.6
8	13.6
9	16.09
10	18.23
11	20.07
12	21.7
13	25.13
14	28.6
15	30.9
16	32.69
17	35.69

Power generation and Voltage monitoring

For this section of the experimental setup, a combination of WRIM and DC motors are used in order to obtain a generation point in the microgrid. This setup, shown in schematic form in **Figure 12**, consists of two variable power supplies, both are capable of outputting AC and DC voltage and vary them thorough manual controls. This characteristic has been used in order to simulate a voltage drop through the phases or a phase disconnect. The WRIM and DC motor are connected through their shaft, meaning they are only mechanically connected, this is necessary in order to control their respective voltage levels separately which provides a greater control. This experimental setup makes use of the characteristic of the WRIM, that enables a switch from power load to power generator when the machine's speed is increased above its asynchronous speed; this is done by accelerating the DC motor so that its speed is translated through the shaft to the WRIM. The physical setup can be seen in **Figure 13.**

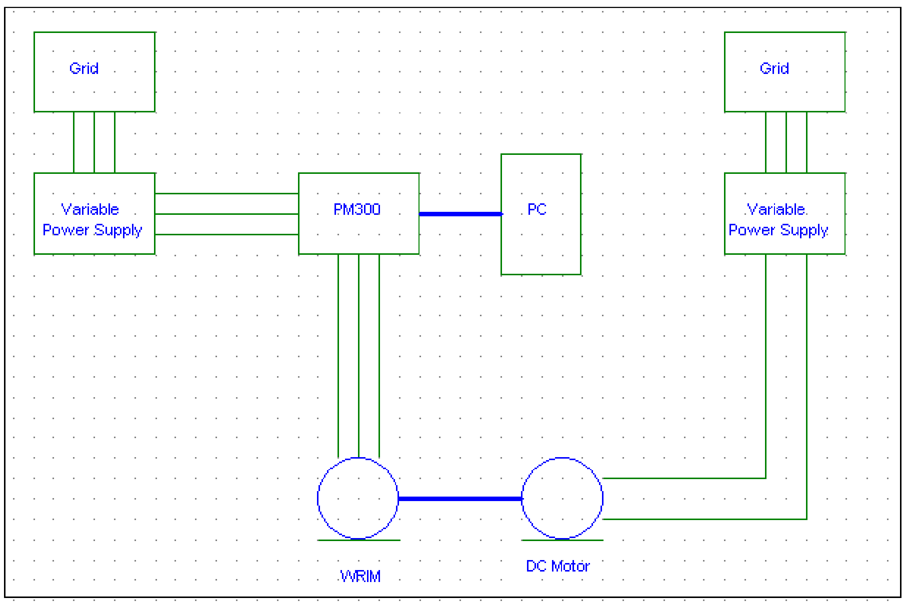


Figure 12: Schematic of Generation point and variable voltage

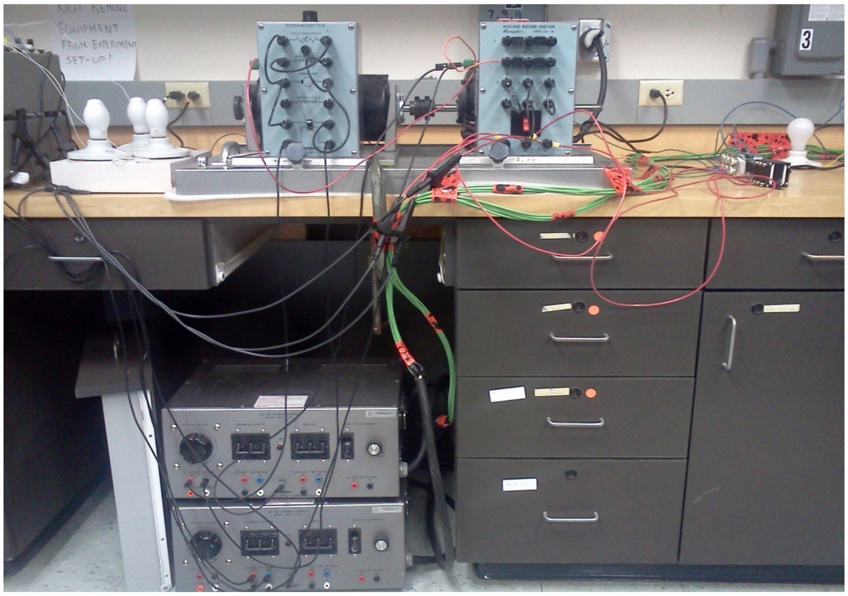


Figure 13: Laboratory implementation of generator and variable voltage

And with the integration of all the previously mentioned systems, the microgrid takes form as shown in schematic form in **Figure 14** and actual laboratory based implementation in **Figure 15.**

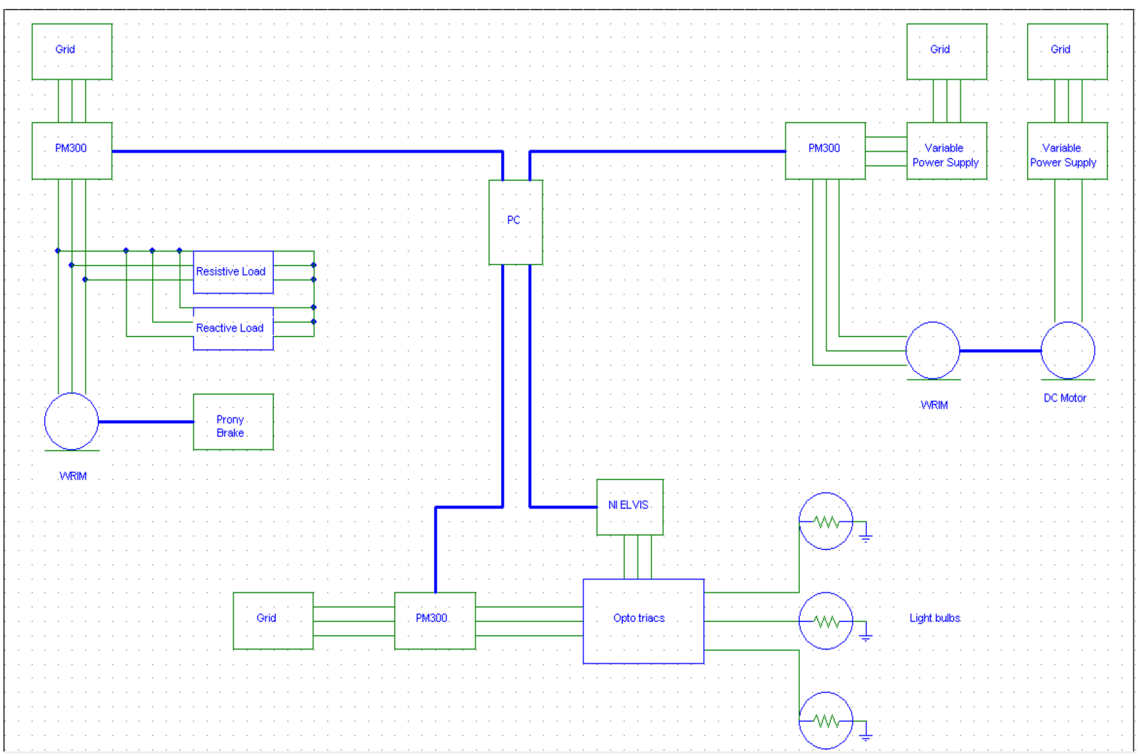


Figure 14: Schematic of smart microgrid

Figure 15: Laboratory based smart microgrid

Software

LabVIEW

In terms of enabling the communication capabilities of the different lab equipment, the choice to use the National Instrument's software LabVIEW was obvious, and it has also been chosen by other authors to perform similar tasks [15]. This software provides an easy drag and drop style of programming; this means that there are already existing functions that can be interconnected in order to perform more complex functions. Also a great advantage of using LabVIEW is that it already includes functions to communicate via IEEE 488.2 interface as well as the NI ELVIS. It also allows for a wide variety of variable types to be used, such as strings, decimal, Boolean, etc. This proved a great asset due to the nature of the communication with the PM 300 which is mainly done by sending and receiving strings containing measurement data, the instructions to the meters were also sent using string-type variables. **Figure 16** shows a portion of the program that handles the communication with the PM 300 meter.

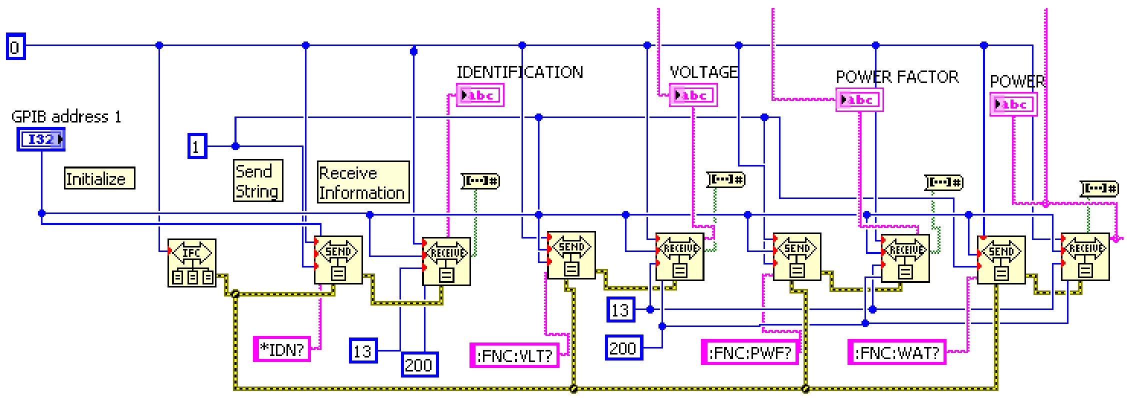


Figure 16: LabVIEW block diagram for communication with PM 300 meter

Since this thesis work is aimed to be an educational tool, it was imperative to produce a compilation of measurements that can be analyzed separately from the LabVIEW program. Once again the answer was found with built in functions provided, it was determined that a CSV (Comma Separated Value) file should be created in order to store the different measurements throughout the run time of the experiment. **Figure 17** shows the portion of the block diagram that performs this function.

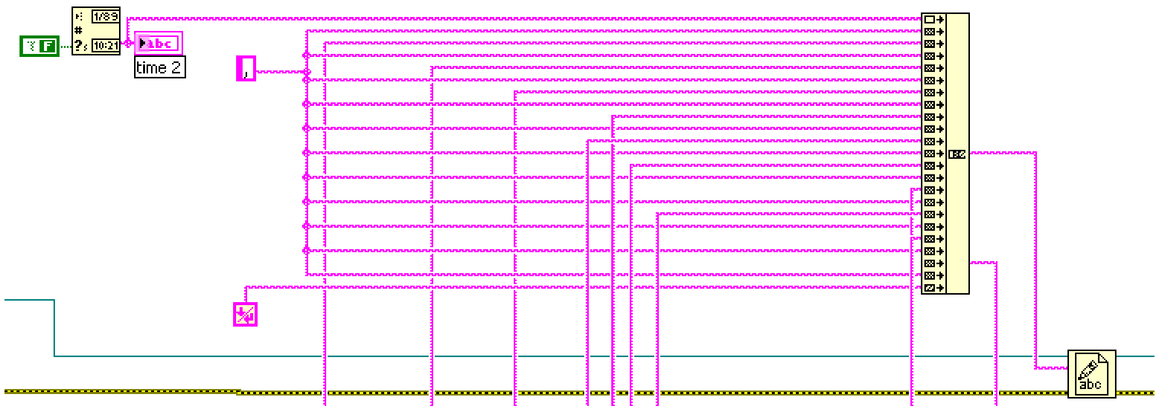


Figure 17: Block Diagram of file writing

Once the CSV file is created, it can be opened with a spreadsheet software, such as Microsoft's Office Excel, in order to make use of the data collected, a more detailed example as to what is contained in this file and some of the results obtained will be described in the next chapter.

MATLAB

When dealing with the logic to disconnect or reconnect non-essential loads, it became apparent that a LabVIEW implementation might not be the best option, and so using one of the functions that allows for another language's code to be executed within LabVIEW, block diagram shown in **Figure 18,** a MATLAB code was created to handle the previously mentioned functions, this resulted in a more compact and efficient implementation. Note that the code shown in **Figure 18** is not the full code; the full code can be seen in **Appendix B**.

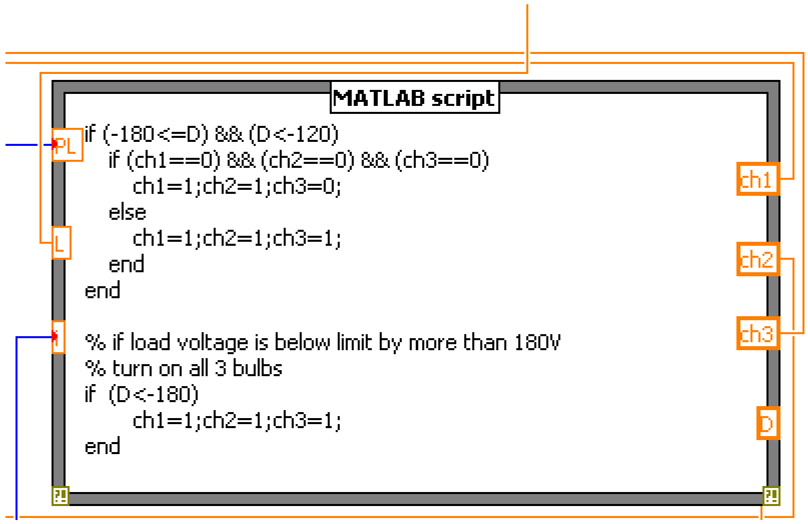


Figure 18: MATLAB script sub-function

This MATLAB script function was used once again in order to calculate the maximum 15 minute power demand measurement, previously discussed in this chapter, and to calculate the final Wh consumption of the system along with the Power Factor bill simulation. Both MATLAB scripts can be seen in their entirety in **Appendix B**.

All of the previously mentioned sections of the program are contained within a timed loop, the user can specify the duration of each iteration by means of indicating the number of minutes per period. **Figure 19** shows a zoomed-out image containing the whole block diagram of the LabVIEW program. Images containing a zoomed-in version of the image can be found in **Appendix A.**

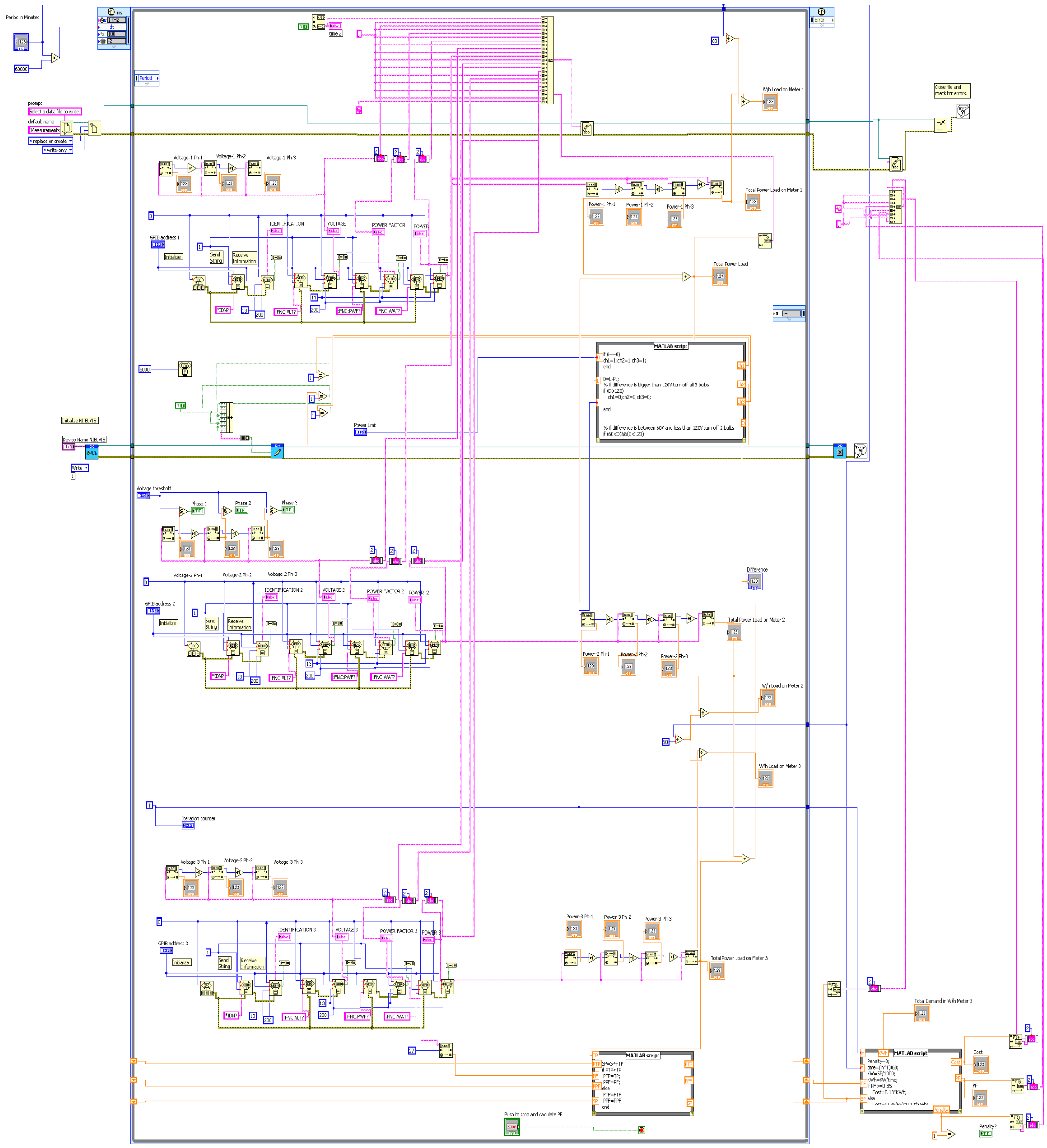


Figure 19: LabVIEW block diagram of smart micro grid system

Graphical User Interface (GUI)

One final characteristic of programming in LabVIEW is that the software provides a GUI (Graphical User Interface) which enables external users to make use of the software without having to modify or even access the block diagram portion. Making full use of this characteristic the user interface was split into two sections, one for a casual monitoring user, and the second one for a more in-depth monitoring; this second section also contains the control panel that is required to configure the program each time before it is set to run.

The control panel is shown in **Figure 20**. It consists of a time monitor panel, this panel displays the hour and minutes by which the program is ruled by. The actual controls consists of the period in minutes, the power limit that rules the disconnect of the non-essential loads, the voltage threshold that triggers the low voltage signal, a dropdown box to select the device connected, in this case the NI ELVIS; if there are more than one device attached, the dropdown list would show them by generic name such as “Dev 1” for one device, “Dev 2” for another one, so on and so forth. There are three GPIB address controls, one for each meter. Each PM 300 can be set to a specific GPIB address that differentiates them from each other, this address can be changed by accessing the meter’s ”output” menu. The last part of the control interface is a “Stop” button, when pushed the program will exit after completing one more loop iteration, and in this case it will access the Power Factor subroutine that calculates the bill.

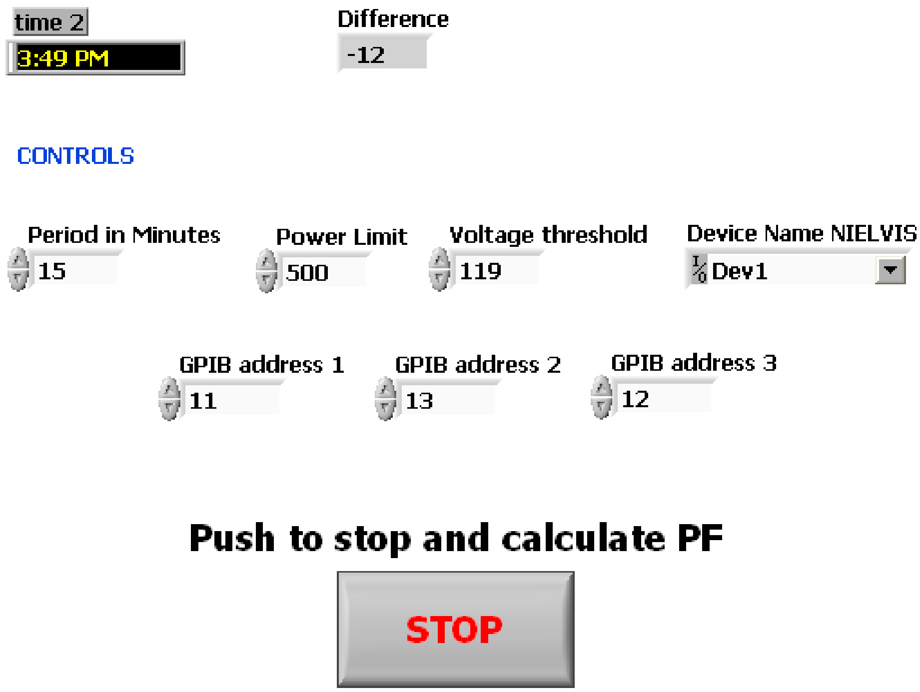


Figure 20: Control portion of the GUI

The monitoring portion of the in-depth section of the GUI, shown in **Figure 21**, contains an iteration counter that shows how many times the program has looped, it shows the "Total Power Load" that is the sum of the three power loads measured by the meters, this total value is a per iteration value, meaning the total power load demanded at that one particular iteration is shown here. The rest of the display contains the raw string measurements coming from the meter; they are raw in the sense that they are displayed exactly as the meter provides them. This is useful in order to rule out a communications malfunction between the program and the meters.

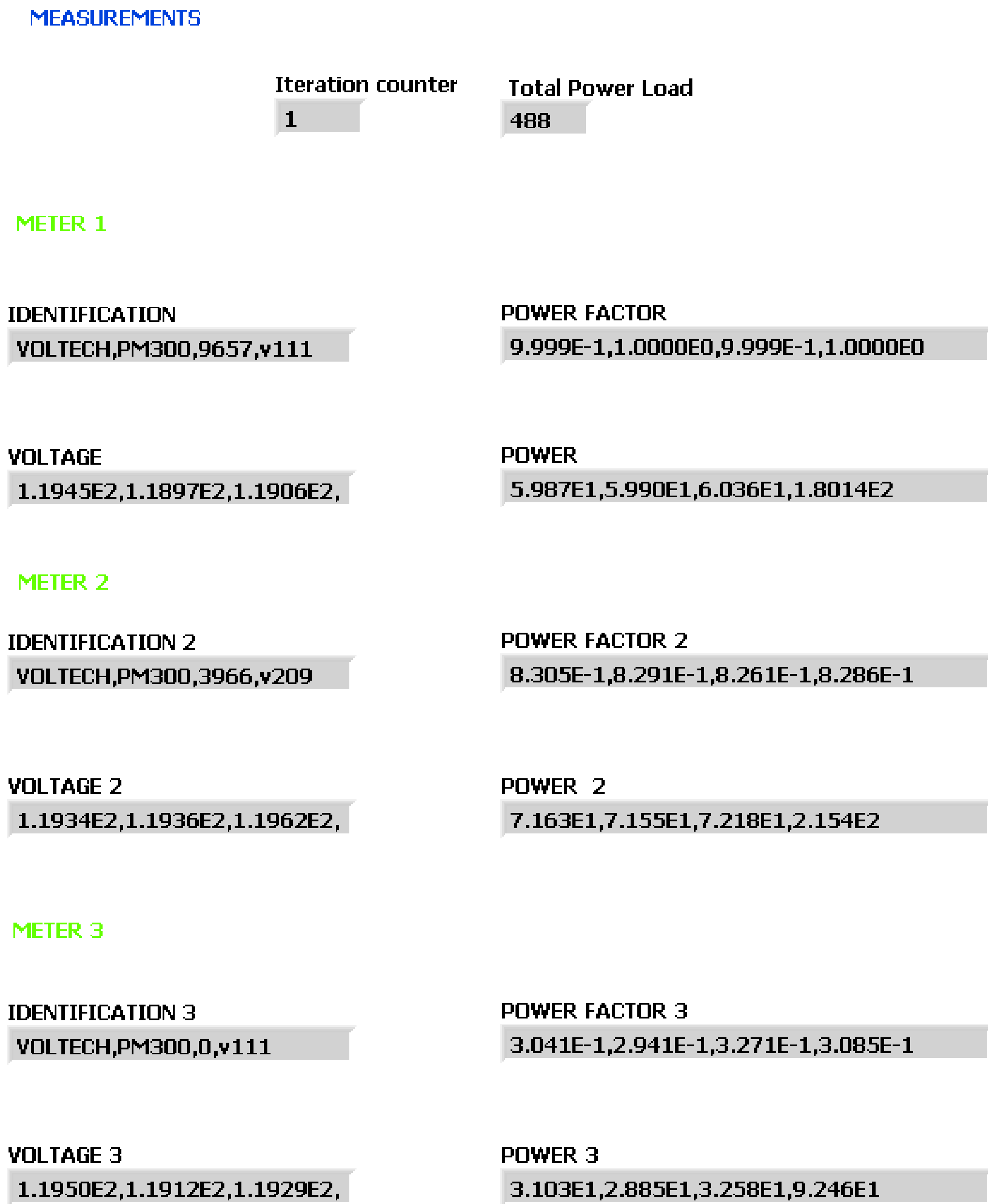


Figure 21: In-depth measurements portion of the GUI

Finally the more casual measurements section of the GUI is shown in **Figure 22**. The voltages and power demand for each of the phases, as well as a Wh consumption and a power demand total are shown for each of the meters. In this representation the string that contains the measurements has been processed and transformed into numerical data in order to provide the user with a clearer cut view of the readings.

Meter 2 section houses three virtual LEDs that represent the alarm for the low voltage detection system, depending on which phase presents the fault, the corresponding LED will light up to alert the user that the voltage has gone below the specified value in the controls.

Below Meter 3 is the Power Factor measurements, this section is calculated at the very end of the program, that is, after the last iteration of the loop is executed. This section shows a total of energy consumed by Meter 3 in Wh. It is only taking into account meter 3, since it is the only one where a control for Power Factor is available. The next display shows the Power Factor that matches the maximum 15 minute power demand measurement, as explained previously, this power factor is used to calculate a cost which is also displayed in this section, the LED labeled “Penalty” refers to the case in which the PF is below 0.85 in which case the LED will be turned on, and vice versa if the PF is above the limit.

Figure 22: Casual measurements portion of the GUI

Procedure

This chapter has shown the different modules that comprise the experimental setup of the smart microgrid. It is because of this that the experimental procedure can be approached to by module, the system allows for an individual function to be active, as well as having all the functions running at the same time, each part of the system will react accordingly. Due to the nature of the equipment, the majority of the adjustments to the loads and generation need to be made by hand by the user.

The first setup necessary to initialize the experiment is the configuration of the LabVIEW program's parameters, through the GUI shown previously in **Figure 20**. These values provided by the user will determine the disconnection of non-essential loads, as well as the low voltage system, along with the time period between measurements. After this initial setup the user can choose to activate one or more of the different subsystems that will trigger the functions of the software. The following are the respective procedures on each said subsystem.

Demand controller

Once the power demand limit has been specified, it is up to the user to increase the overall power demand in order to reach and surpass the limit. This can be done by increasing the torque applied to the WRIM, which in this case is considered the essential load of the system, by the Prony brake by adjusting it accordingly; this will oppose mechanical resistance to the rotor and increase power demand. Due to the mechanical nature of the brake, some heating may occur. Another option is to connect some of the resistive loads to the stator; this will again increase power demand. Of course a combination of both will result of a greater increase in power demand; this system is shown in **Figure 10**.

When the power load has reached or exceeded the limit, the software will react and disconnect one, two, or three loads, depending on the amount of increased demand.

In order for the system to reconnect the loads, the demand must be decreased, this can be done by simply releasing the prony brake to a free spin state, disconnect resistive loads or by engaging the generator to inject power and lower overall demand.

Generation point

This system consists of two motors, one WRIM and one DC, schematic is shown in **Figure 12**. Once active the user can regulate the voltage flowing into both machines by adjusting their respective variable power supplies. Initially the system will be considered as another three phase load, since the WRIM functions normally as such. In order to change this behavior both machines must be provided with their rated voltage, for both the value is 120V however for the WRIM this number represents a phase voltage since it is necessary to supply AC voltage, whereas the DC motor is 120V DC. At this point the system will still behave as a load; one final adjustment is needed from the field rheostat that is internally connected to the stator of the DC motor. Adjusting this will allow the

DC motor to drive the WRIM to exceed its rated speed, or asynchronous speed, in this case 1800rpms, this will engage the generation behavior needed to inject power into the grid as opposed to draw from it. The amount of power generated will depend on the setting of the field rheostat.

Power Factor variation

This subsystem is implemented along with the demand controller's essential load. **Figure 10** has a schematic view. For this function of the microgrid, the reactive power must be varied by applying reactive loads such as inductors to increase the reactive power value, and capacitors to decrease it [12]. However it is noteworthy to remember that the PF value used to determine the penalty is dependent on the maximum demand measurement.

Low Voltage detection

This monitoring system is implemented in the WRIM used in the generation point, in order to test this feature, it is necessary to vary the input voltage coming from the variable power supply, as long as the voltage level is below the user-specified voltage limit, the virtual LED in the GUI will light up, this is of course true for a reading of no voltage as well.

CHAPTER V

RESULTS & DISCUSSION

Preliminary Tests

Demand Controller. Due to the nature of the experimental setup, several tests were done to ensure the functionality of the different modules before the microgrid was tested as a whole. The first of said tests was the demand controller subsystem. This was the first to be implemented and therefore tested. At the time it was decided to run the experiment for a period of 12 hours continuously, this amount of time would provide with a suitable amount of sample points, which were taken every 15 minutes. **Figure 23** contains a graph plotted with said measurements; several more tests were performed under these settings, their results can be observed in **Appendix C;** there is also a constant line to indicate where the demand limit is. From this it was observed that when the demand was increased beyond the specified limit, the demand controlled circuit disconnected non-essential loads to bring the level down. Once the total demand was well below the limit, the system reconnected the previously shed loads, and the system resumed its normal levels of operation. This test also provided confidence that the equipment could handle extended periods of time of continuous operation, as well as the computer software and photo-triac circuit.

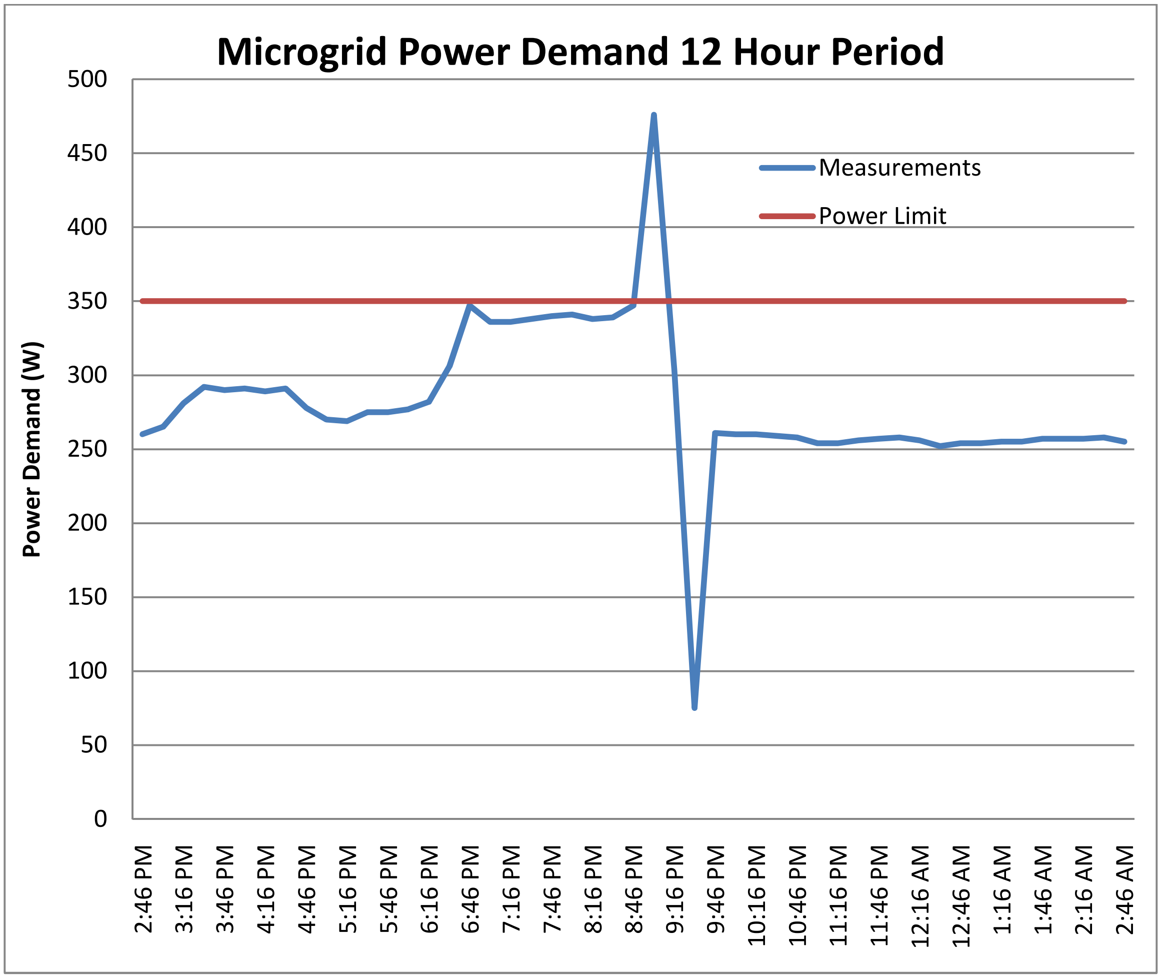


Figure 23: 12 Hour testing of Demand Controller System

Generation point. In order to establish an idea of the level of generation that could be achieved with the setup consisting of the equipment depicted in **Figure 13** a trial run was effected with the software measuring only that point in the microgrid. Since this test was only to establish a base idea, the measurements were taken every minute for a period of one half hour. **Figure 24** holds the results.

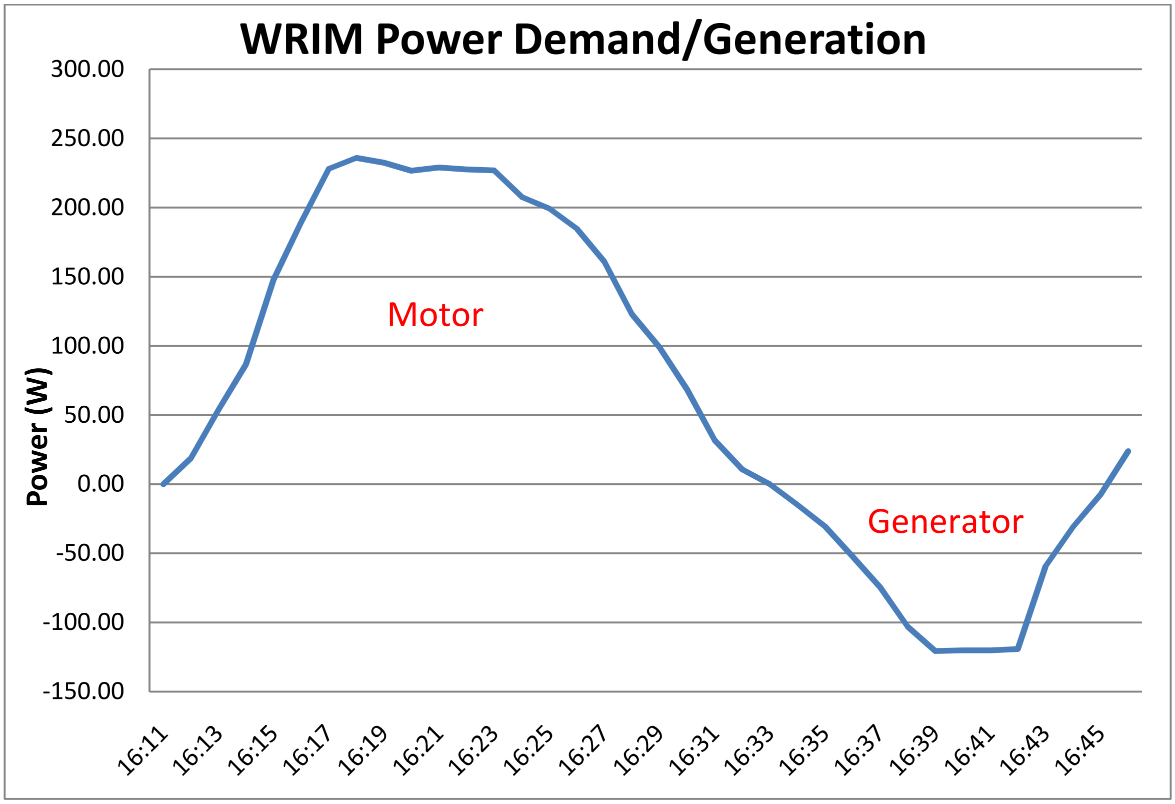


Figure 24: Generator testing results

With this it is easy to observe the behavior of the set up, where the system behaves as a three phase load before the asynchronous speed of the wound rotor motor is achieved, once said speed is surpassed the generation behavior commences, depicted in the previous figure by negative power readings. This allowed for total demand to be lowered in further testing without having to disconnect loads such as the prony brake or the variable resistances.

Microgrid testing

Once the preliminary tests were completed, the various subsystems were integrated into the final presentation of the microgrid, and under this compiled architecture new testing scenarios began. For this stage 24 hour testing periods were determined in order to have a sufficient sample points and ample time in order to test all of the different functions of the smart microgrid. **Table 3** shows a subset of the measurements file, the format presented is the format that is received from the PM 300 meters, **Table 4** shows the same subset of information, with slight modifications to the format which have proven to be beneficial in order to make the information more legible.

By observing these measurement files it is determined that the implementation to only have voltage, power factor, and power demand be recorded for each meter, was an accurate, even with just these 3 basic measurements the files generated contain a vast number of information, that can give way to further calculations such as reactive power, phase current, etc. This size is also the reason they cannot be properly shown in the following tables. Instead graphs have been generated in order to digest the information in a more visual manner. **Figure 25** holds the plot representing the demand results from one of the 24 hour testing periods. **Figure 26** has been created in order to further clarify the events that occurred during the test, and how the system responds.

Table 3: Subset of raw measurement data file

5:25 PM	1.21E+02	1.20E+02	1.20E+02	2.09E+02	1.00E+00	1.00E+00	1.00E+00	1.00E+00
5:40 PM	1.20E+02	1.20E+02	1.20E+02	2.08E+02	1.00E+00	1.00E+00	1.00E+00	1.00E+00
5:55 PM	1.21E+02	1.20E+02	1.20E+02	2.09E+02	1.00E+00	1.00E+00	1.00E+00	1.00E+00
6:10 PM	1.21E+02	1.21E+02	1.20E+02	2.09E+02	1.00E+00	1.00E+00	1.00E+00	1.00E+00
6:25 PM	1.21E+02	1.21E+02	1.21E+02	2.09E+02	1.00E+00	1.00E+00	1.00E+00	1.00E+00
6:40 PM	1.21E+02	1.21E+02	1.21E+02	2.10E+02	1.00E+00	1.00E+00	1.00E+00	1.00E+00
6:55 PM	1.22E+02	1.21E+02	1.21E+02	2.10E+02	1.00E+00	1.00E+00	1.00E+00	1.00E+00
7:10 PM	1.22E+02	1.21E+02	1.21E+02	2.10E+02	1.00E+00	1.00E+00	1.00E+00	1.00E+00
7:25 PM	1.22E+02	1.21E+02	1.21E+02	2.10E+02	1.00E+00	1.00E+00	1.00E+00	1.00E+00
7:40 PM	1.22E+02	1.21E+02	1.21E+02	2.11E+02	1.00E+00	1.00E+00	1.00E+00	1.00E+00
7:55 PM	1.22E+02	1.21E+02	1.21E+02	2.10E+02	1.00E+00	1.00E+00	1.00E+00	1.00E+00
8:10 PM	1.22E+02	1.21E+02	1.21E+02	2.10E+02	1.00E+00	1.00E+00	1.00E+00	1.00E+00
8:25 PM	1.22E+02	1.21E+02	1.21E+02	2.10E+02	1.00E+00	1.00E+00	1.00E+00	1.00E+00

Table 4: Subset of formatted measurement data file

	METER 1											
	VOLTAGE				POWER FACTOR				POWER			
	1	2	3	LINE	1	2	3	∑	1	2	3	∑
5:35 PM	120.92	120.75	120.61	209.20	1.00	1.00	1.00	1.00	0.00	0.00	0.00	0.00
5:50 PM	121.11	120.77	120.63	209.30	1.00	1.00	1.00	1.00	61.19	61.32	61.63	184.14
6:05 PM	121.52	121.00	121.04	209.90	1.00	1.00	1.00	1.00	61.51	61.51	61.96	184.98
6:20 PM	121.54	121.08	121.03	210.00	1.00	1.00	1.00	1.00	61.51	61.57	61.94	185.03
6:35 PM	121.00	120.57	120.48	209.00	1.00	1.00	1.00	1.00	61.11	61.16	61.51	183.79
6:50 PM	121.19	120.70	120.66	209.30	1.00	1.00	1.00	1.00	61.25	61.25	61.65	184.16
7:05 PM	119.85	119.45	119.40	207.10	1.00	1.00	1.00	1.00	60.22	60.29	60.66	181.19
7:20 PM	119.99	119.54	119.46	207.30	1.00	1.00	1.00	1.00	60.34	60.36	60.70	181.39
7:35 PM	120.24	119.64	119.66	207.60	1.00	1.00	1.00	1.00	60.55	60.45	60.88	181.88
7:50 PM	120.43	119.81	119.83	207.90	1.00	1.00	1.00	1.00	60.67	60.59	61.00	182.26
8:05 PM	121.39	120.87	120.93	209.70	1.00	1.00	1.00	1.00	61.41	61.39	61.86	184.66
8:20 PM	121.36	120.86	120.85	209.60	1.00	1.00	1.00	1.00	61.39	61.39	61.81	184.59
8:35 PM	121.40	120.89	120.83	209.60	1.00	1.00	1.00	1.00	61.41	61.40	61.78	184.59

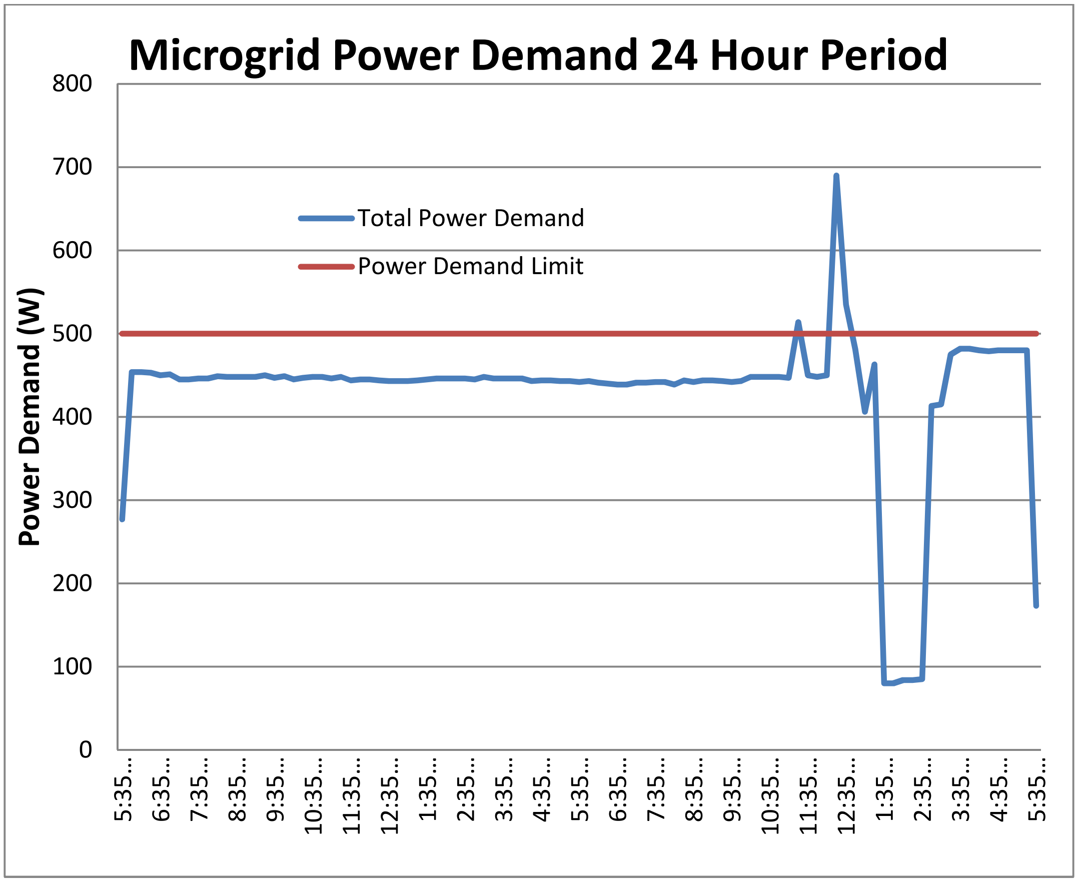


Figure 25: power demand measurements during a 24 hour test period

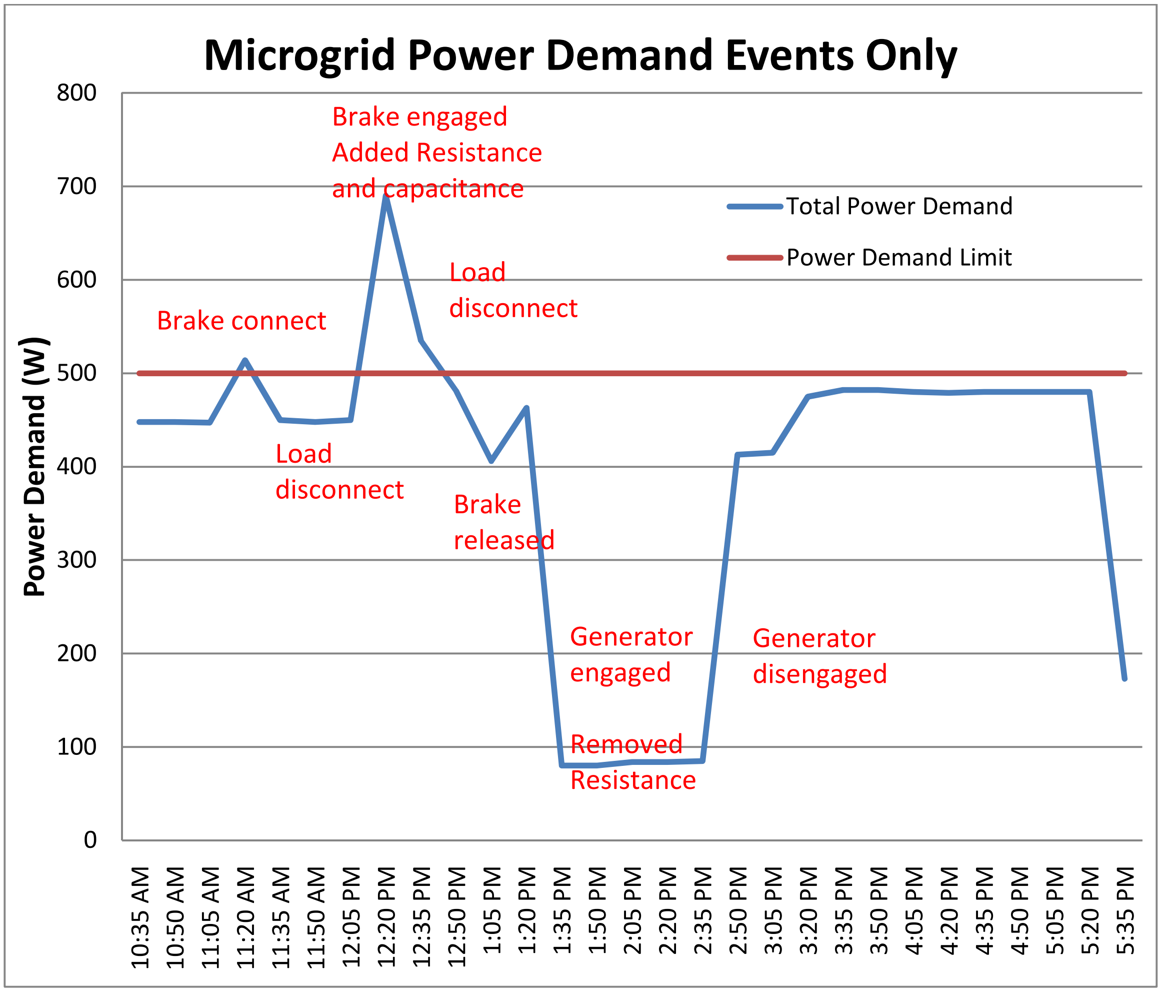


Figure 26: power demand events during 24 hour testing period with log of activities

With the information provided by the previous graph, it was determined that the implementation of the demand controller and generation point functions of the microgrid have been successful.

Several more such tests were performed; the resulting graphs are shown in **Appendix C**.

From the same set of measurements a plot for PF measurements has been created in **Figure 27**. It is shown that the highest value PF matches the highest value of demand measurement shown in **Figure 25.** This particular case was above the PF limit and thus did not incur in a penalty when the bill calculation was performed at the end of the test run. Another such graph is shown in **Figure 28,** which belongs to another set of test measurements, in which the PF was held below the previously mentioned limit, and thus the second scenario, where the penalty is incurred, is executed.

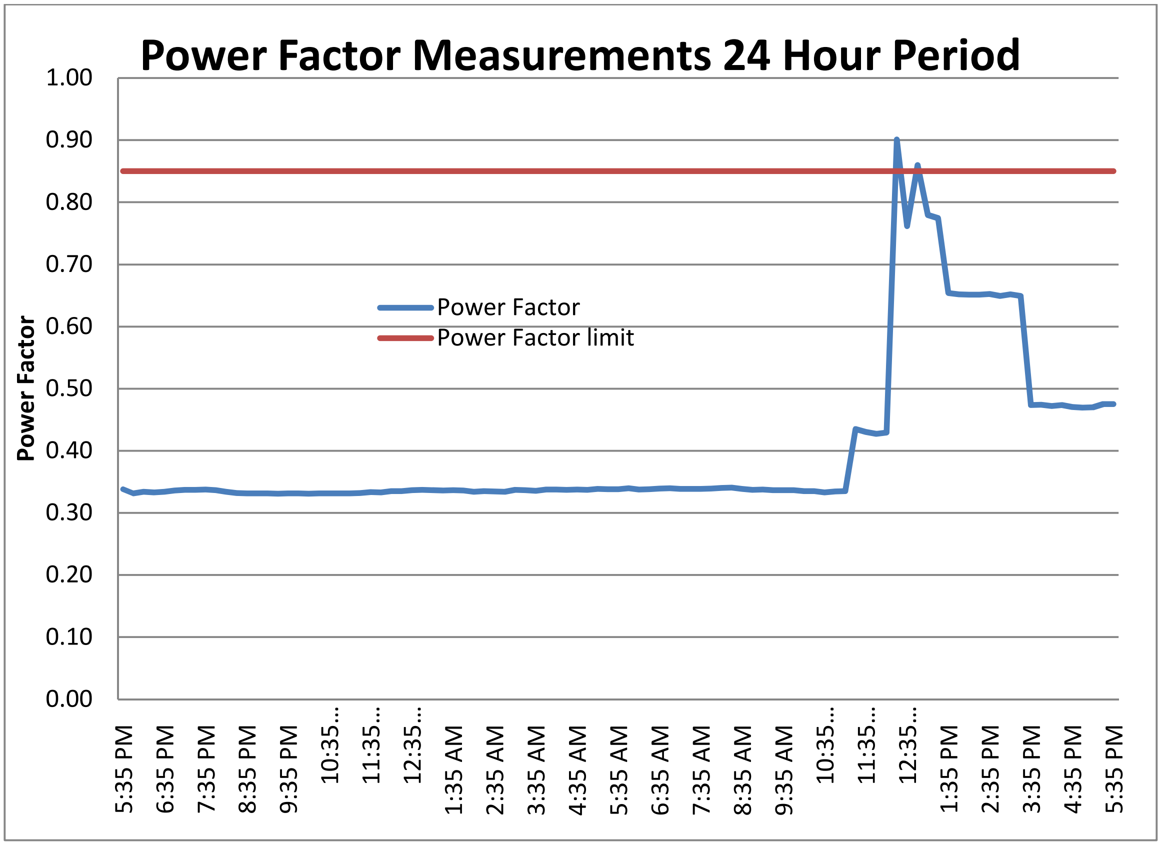


Figure 27: power factor measurements during 24 hour testing period

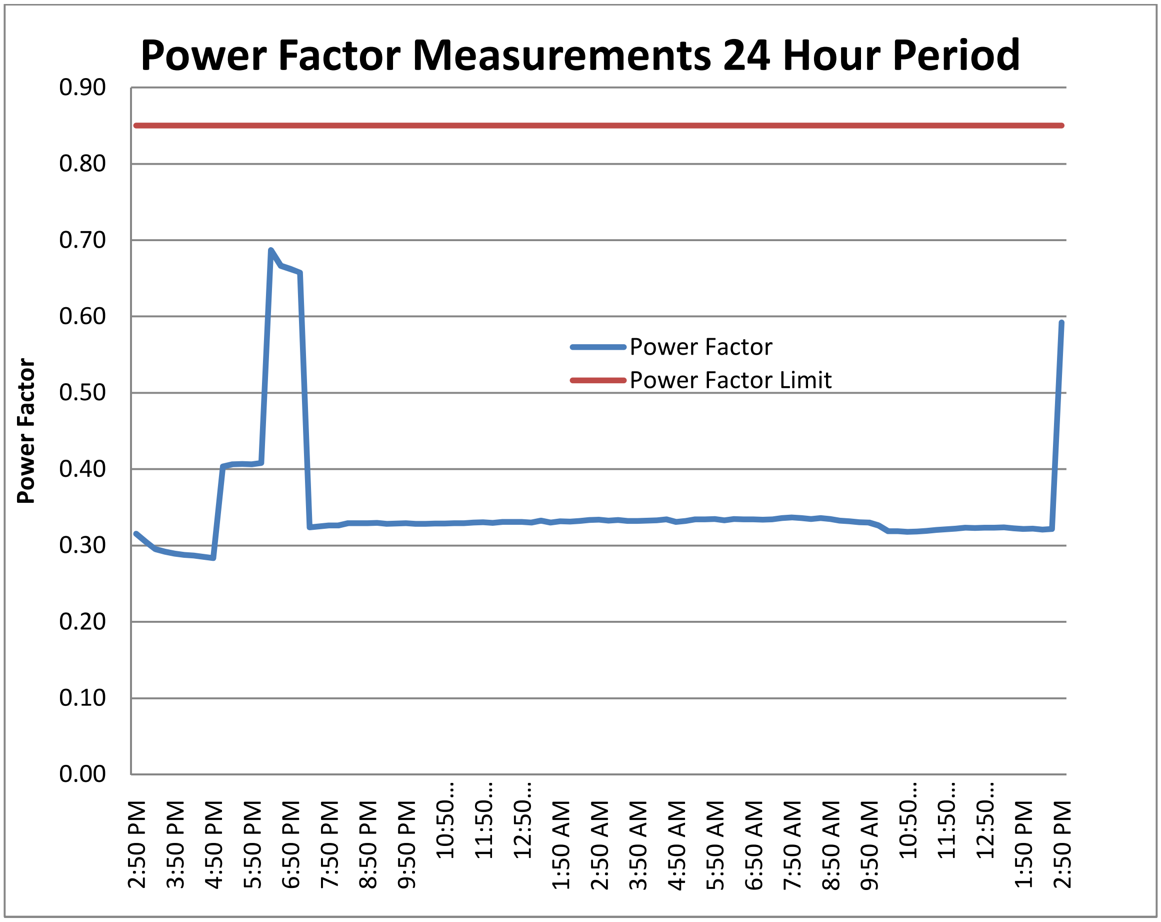


Figure 28: Second scenario for PF measurements during 24 hour testing period

CHAPTER VI

CONCLUSIONS

The last few years have seen a steep increase in the renewable energy and energy efficiency fields. This reaches across all sectors of energy handling, from generation, distribution and consumers. The necessity for smart solutions to problems inherited by the past is pressing across all sectors of the energy industry, as well as governments, international organization and of course, universities all around the globe. The undertaking that represents an overhaul of the existing power grid is a challenging one, to say the least, and even though great advances have been made in regards of the previously mentioned fields, there is still an enormous amount of work and research to be done, this translates into more time applied to the search of new technologies that can provide solutions at a cost effective rate. Thus it is necessary for the future generation of the industry to become aware of current technologies that can potentially address the needs of the future power grid, while they are still in their student stage. With this in mind, the work presented in this thesis aims at providing a stepping stone to aid the upcoming generations of students to become familiar with some of the concepts and technologies that are currently being deployed by the industry. Some of these concepts are implemented in this laboratory based smart microgrid: Voltage monitoring in real time, two way communication with load points, data recording, injecting power into the grid, the use of demand controlled circuits that can lower demand as the user sees fit, and monitoring of PF.

All of these concepts, here present, can be integrated into laboratory activities of different courses already offered in the engineering curriculum, such as power systems, electrical and electronics circuits, and more importantly, renewable energy; for it seems that the development of a new smart power grid is mainly driven by the integration of renewable green energy production technologies, such as photovoltaic arrays, wind turbines, and bio mass boilers, amongst many others. The benefit to students is widespread, for if they decide to continue their studies into graduate school, there are many universities that have partnerships in order to perform research on these subjects, and if they decide to join the workforce, it will be an edge to be already somewhat familiar with the technology and process that the energy industry is already implementing, many of which are driven by funding by governments who are looking to lower their carbon emission, or to replace old generation plants with more environmental friendly ones, and still be able to service the increasing population of their respective countries.

And so, while the objectives set for this thesis were met, this study represents a first step into a much wider, expanding and uncharted territory that is the smart power grid.

REFERENCES

[1] H. Farhangi. The path of the smart grid. *IEEE Power and Energy Magazine*, 8(1):18–28, January/February, 2010

[2] D. A. Cohen, "GridAgents: Intelligent agent applications for integration of distributed energy resources within distribution systems," *IEEE Power and Energy Society 2008 General Meeting: Conversion and Delivery of Electrical Energy in the 21st Century,* 2008

[3] H. Farhangi, " Intelligent Micro Grid research at BCIT," *2008 IEEE Electrical Power and Energy Conference - Energy Innovation*, 2008

[4] A. Ricci, B. Vinerba, E. Smargiassi, I. De Munari, V. Aisa, P. Ciampolini "Power-grid load balancing by using smart home appliances," *IEEE International Conference on Consumer Electronics*, 2008

[5] J. M. Guerrero, J. C. Vasquez, J. Matas, L. García de Vicuña, and M. Castilla, "Hierarchical control of droop-controlled AC and DC microgrids–A general approach towards standardization," *35th Annual Conference of the IEEE Industrial Electronics Society,* p 4305-4310, 2009

[6] M.A. El-Sharkawi, "Integration of renewable energy in electrical engineering curriculum" *IEEE PES General Meeting*, p 1-4, July 2009

[7] A. Molderink, V. Bakker, M.G. Bosman, J.L. Hurink, G.J.M. Smit "Simulating the effect on the energy efficiency of smart grid technologies," *Proceedings - Winter Simulation Conference*, p 1530-1541, 2009

[8] S. Bala, G. Venkataramanan, "Autonomous power electronic interfaces between microgrids," *2009 IEEE Energy Conversion Congress and Exposition,* 3006-3013, 2009

[9].Ricci, A. Vinerba, B. Smargiassi, E. De Munari, I. Aisa, V. Ciampolini, "Power-grid load balancing by using smart home appliances" *2008 Digest of Technical Papers International Conference on Consumer Electronics, The Mobile Consumer, ICCE 2008*

[10] P.K. Lee, L.L. Lai, "Smart metering in micro-grid applications," *2009 IEEE Power and Energy Society General Meeting*, 2009

[11] P.K. Lee, L.L. Lai, "A practical approach of smart metering integration in micro-grid," IEEE PES General Meeting, Minneapolis, MN, PES 2010

[12] P. Tenti, H.K Morales Paredes, F.P. Marafão, P. Mattavelli, "Accountability and revenue metering in smart micro-grids," *2010 IEEE International Conference on Applied Measurements for Power Systems*, p 74-79, 2010

[13] G. Chicco, "Challenges for smart distribution systems: Data representation and optimization objectives," *Proceedings of the International Conference on Optimization of Electrical and Electronic Equipment*, p 1236-1244, 2010

[14] R. W. Wies, " Design of an energy-efficient standalone distributed generation system employing renewable energy sources and smart grid technology as a student design project," *IEEE PES General Meeting*, Minneapolis, MN, 2010

[15] O.A. Mohammed, M.A. Nayeem, A.K. Kaviani, "A laboratory based microgrid and distributed generation infrastructure for studying connectivity issues to operational power systems," *IEEE PES General Meeting*, 2010

[16] N.C.F.Tse, W.H. Lau, J.Y.C. Chan, "ZigBee based smart metering network for monitoring building integrated electric vehicle charging circuits," *IEEE PES General Meeting*, 2010

[17] S. Suryanarayanan, J. Mitra, R.K. Rietz "A framework for energy management in customer-driven microgrids," *IEEE PES General Meeting*, 2010

[18] P. Tatcho, Y. Zhou, H. Li, L. Liu, "A real time digital test bed for a smart grid using RTDS," *2nd International Symposium on Power Electronics for Distributed Generation Systems*, p 658-661, 2010

[19] J. Y. Huang, P. Wang, Y. Ding, P. Loh, L. Goel, "Demand side load management of smart grids using intelligent trading/metering/billing system," ," *IEEE PES General Meeting*, 2010

[20] W. Caisheng, H. Nehrir, L. Feng, Z. Junhui, "From Hybrid Energy Systems to Microgrids:Hybridization Techniques, Configuration, and Control," *IEEE PES General Meeting*, p. 1-4, July 2010

[21] A. Molderink, V. Bakker, M.G. Bosman, J.L. Hurink, G.J.M. Smit "Management and control of domestic smart grid technology," *IEEE Transactions on Smart Grid*, v 1, n 2, p 109-119, September 2010

[22] C. Marinescu, A. Deaconu, E. Cirurea, D. Marinescu, “Modeling and simulating using graphs part 1 active power flow,” *12th International Conference on Optimization of Electrical and Electronic Equipment*, p 1245-1250, May 2010

[23]C. Marinescu, A. Deaconu, E. Cirurea, D. Marinescu, “Modeling and simulating using graphs part 2 optimization of reactive power,” *12th International Conference on Optimization of Electrical and Electronic Equipment*, p 1245-1250, May 2010

[24] V. Calderaro, V. Galdi, A. Piccolo, P. Siano, “Improving reliability system by optimal sectionaliser placement in smart distribution grid,” *IEEE International Symposium on Industrial Electronics*, p 2530-2536, 2010

[25] M. Pipattanasomporn, H. Feroze, S. Rahman, “Multi-agent systems in a distributed smart grid: Design and implementation,” *2009 IEEE/PES Power Systems Conference and Exposition,* 2009

[26] Z. Xu, X. Li, “The construction of interconnected communication system among smart grid and a variety of networks,” *2010 Asia-Pacific Power and Energy Engineering Conference*, 2010

[27] http://www.voltech.com/products/poweranalyzers/PM300.aspx

[28] *Voltech IEEE488 Interface for the PM100 and PM300 Power Analysers*. Voltech, 1996. Pp 2.

[29] http://zone.ni.com/devzone/cda/tut/p/id/7159

[30] *City of Austin Electric Rate Schedule*. Austin Energy. Austin, TX, 2010.

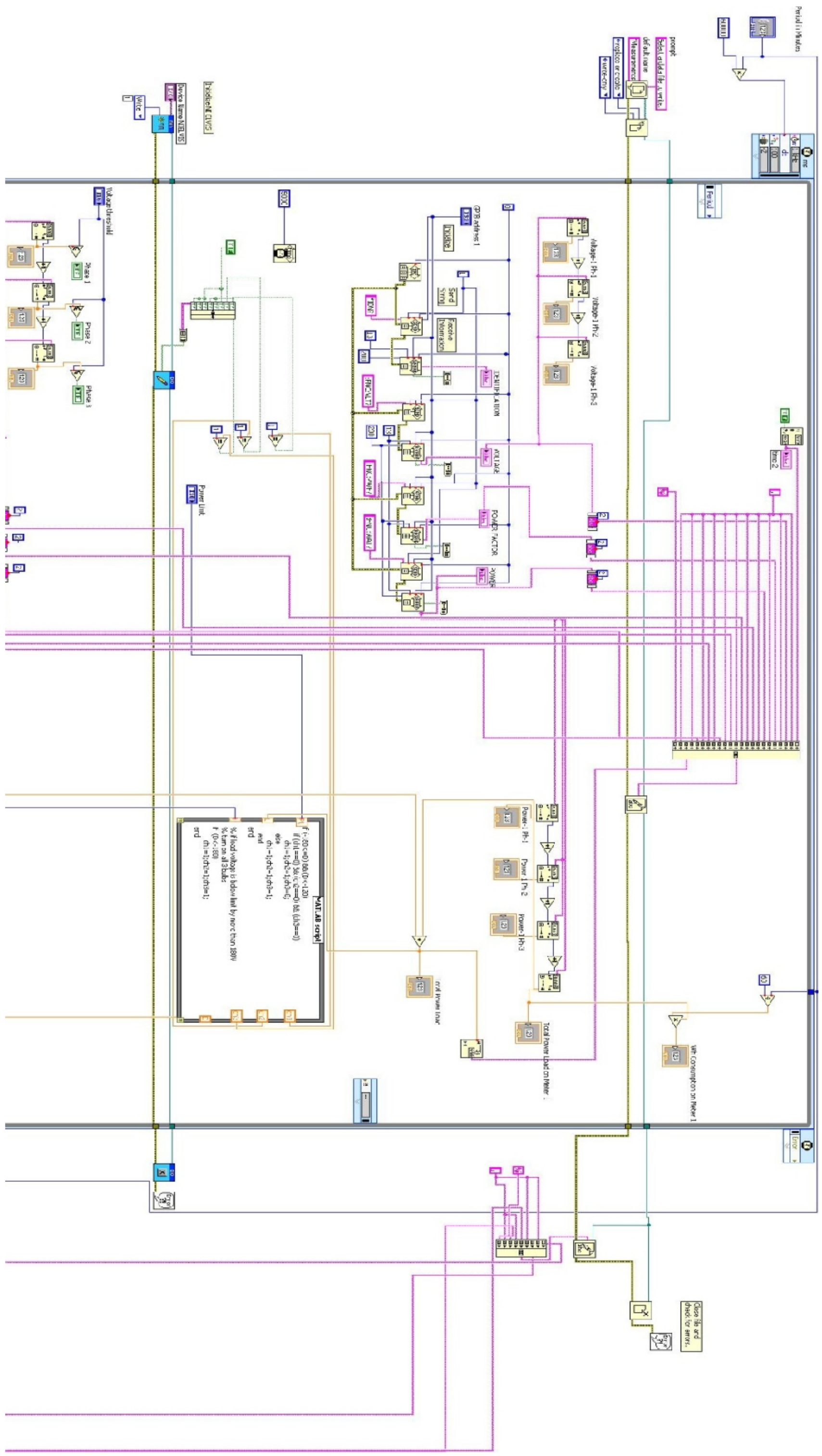
[31]Ramos, J., Aguilera, L., Garcia, R., Sanchez, J., “Commissioning a 5 kW PV Array for Electrical Engineering University Curriculum” *2011 ASEE Annual Conference & Exposition,* Vancouver, BC, Canada, 2011

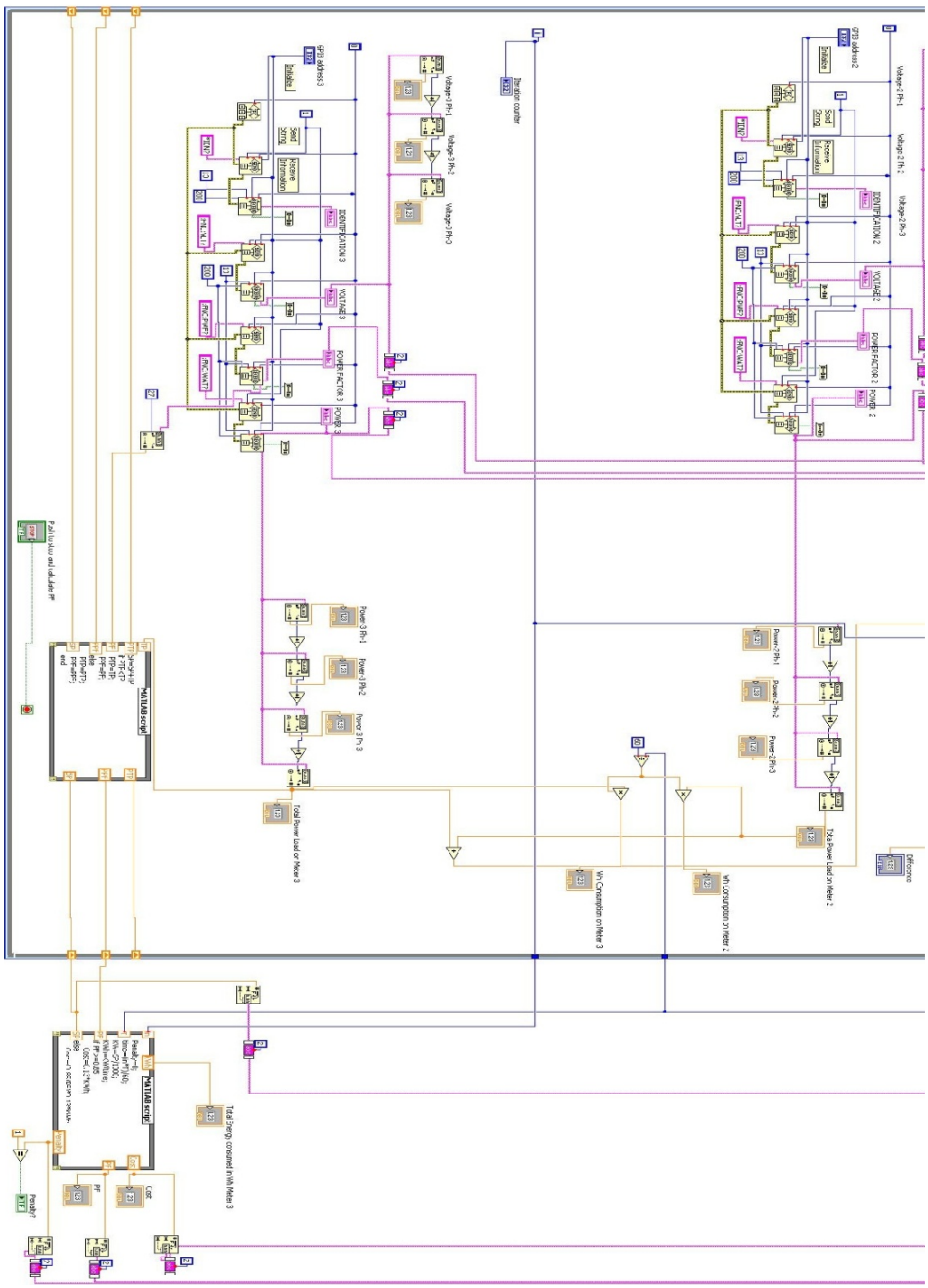
[32] http://en.wikipedia.org/wiki/Power_factor

APPENDIX A

APPENDIX A

LABVIEW





APPENDIX B

APPENDIX B

MATLAB

MATLAB code for load disconnect/reconnect

```
if (i==0)
ch1=1;ch2=1;ch3=1;
end

D=L-PL;
% if difference is bigger than 120V turn off all 3 bulbs
if (D>120)
    ch1=0;ch2=0;ch3=0;

end


% if difference is between 60V and less than 120V turn off 2 bulbs
if (60<D)&&(D<120)
    if (ch1==1)
        ch1=0;ch2=0;
    else if (ch1==0)
            ch2=0;ch3=0;
        end; end; end

% if difference is between 0V and less than 60V turn off 1 bulbs
if (0<D)&&(D<60)
    if (ch1==1)
        ch1=0;
    else if (ch1==0) && (ch2==1)
            ch2=0;
        else (ch1==0) && (ch2==0)
            ch3=0;
        end; end; end;

% if load voltage is below limit by less than 60V, maintain bulb state
if (D<0) && (-60<=D)
       ch1=ch1; ch2=ch2; ch3=ch3;
end


% if load voltage is below limit by more than 60V and less than 120V
```

```
% turn on 1 bulb
if (-120<=D) && (D<-60)
   if (ch2==1) && (ch3==1)
        ch1=1;ch2=1;ch3=1;
    else if (ch1==0) && (ch2==0) && (ch3==1)
            ch1=0;ch2=1;ch3=1;
        else if (ch1==0) && (ch2==0) && (ch3==0)
            ch1=0;ch2=0;ch3=1;
            end
        end
    end
end

% if load voltage is below limit by more than 120V and less than 180V
% turn on 2 bulbs
if (-180<=D) && (D<-120)
    if (ch1==0) && (ch2==0) && (ch3==0)
        ch1=1;ch2=1;ch3=0;
    else
        ch1=1;ch2=1;ch3=1;
    end
end

% if load voltage is below limit by more than 180V
% turn on all 3 bulbs
if  (D<-180)
        ch1=1;ch2=1;ch3=1;
end
```

MATLAB code for determination of maximum power demand measurement

```
SP=SP+TP      %Sum of Power = Sum of Power + Total Power from iteration
if PTP<TP               % PTP: Previous Total Power
        PTP=TP;         %TP: Total Power for current iteration
        PPF=PF;         %PPF: Previous Power Factor
Else                    %PF: Power Factor for current iteration
        PTP=PTP;
        PPF=PPF;
end
```

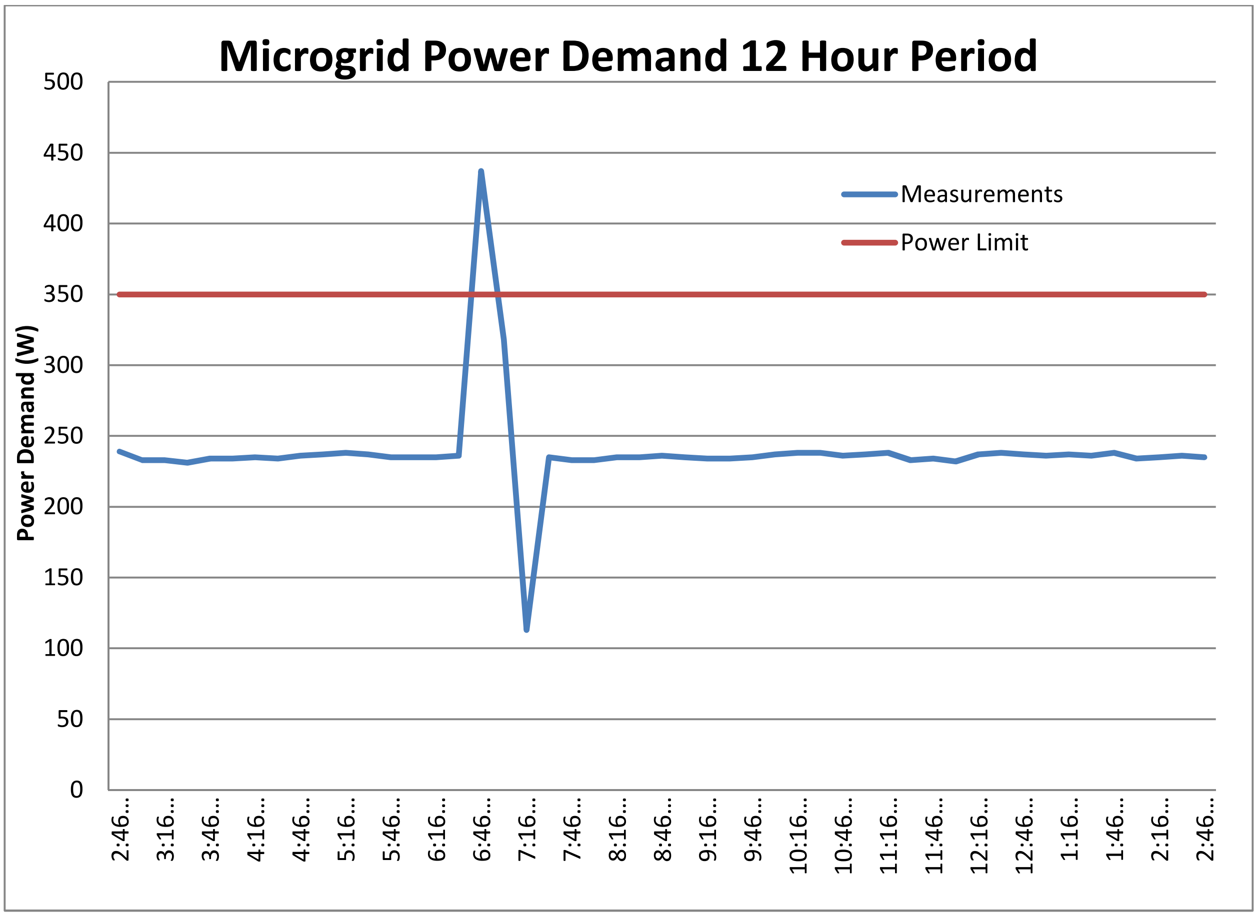
MATLAB code for calculation of energy bill including power factor

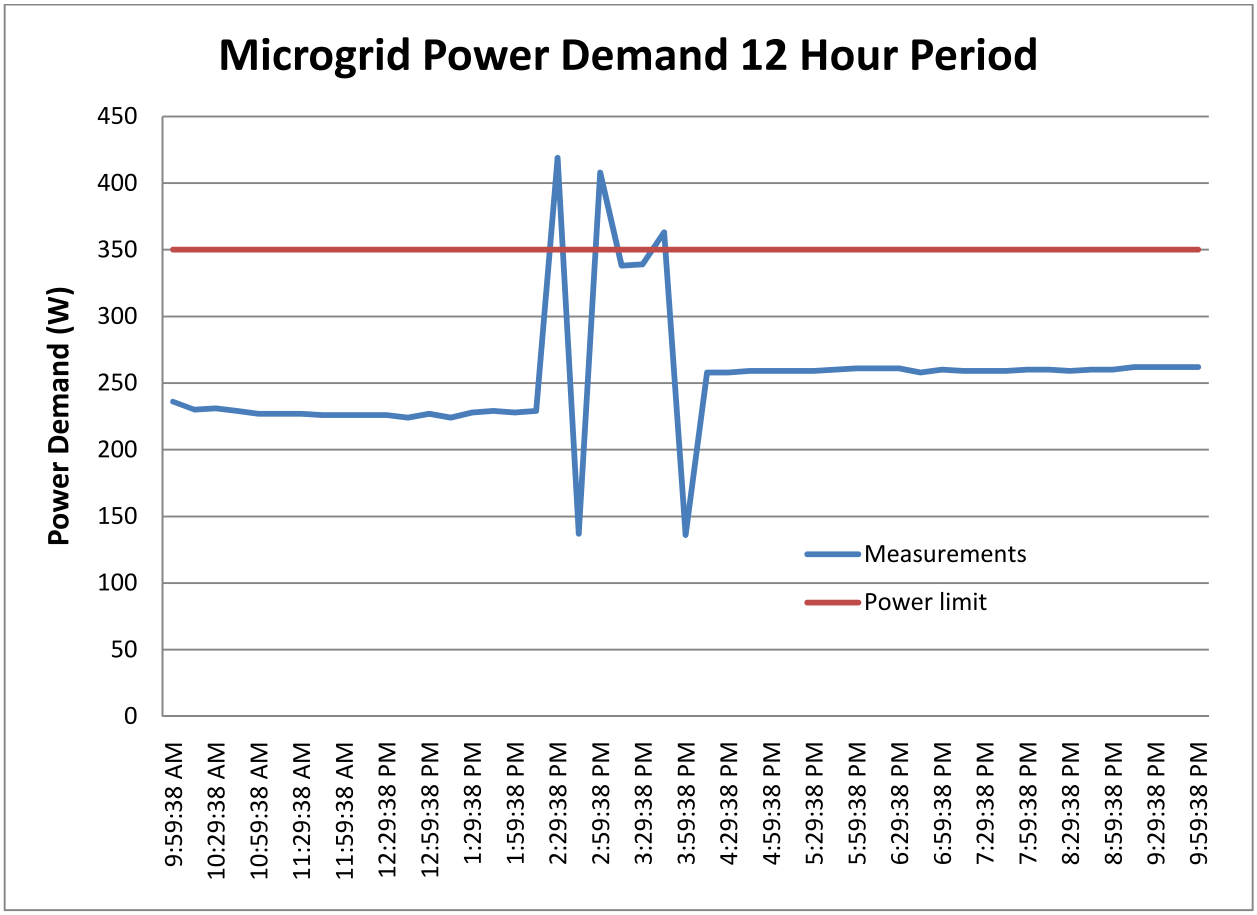
```
Penalty=0;              %Penalty indicator
time=(in*T)/60;         %Time=(number of iterations * Minutes in each period)/60
KW=SP/1000;             %Kilowatts = Sum of Power demands/1000
KWh=KW*time;            %Calculation of Kilowatt Hour consumed
if PF>=0.85             %Process to determine if PF incurs in penalty or not
   Cost=0.13*KWh;
else
   Cost=(0.85/PF)*0.13*KWh;
   Penalty=1;
end;
```

APPENDIX C

APPENDIX C

ADDITIONAL TEST RESULTS




Microgrid Power Demand 12 Hour Period
Power Demand (W)
450
400
350
300
250
200
150
100
50
0
Measurements
Power limit
9:59:38 AM
10:29:38 AM
10:59:38 AM
11:29:38 AM
11:59:38 AM
12:29:38 PM
12:59:38 PM
1:29:38 PM
1:59:38 PM
2:29:38 PM
2:59:38 PM
3:29:38 PM
3:59:38 PM
4:29:38 PM
4:59:38 PM
5:29:38 PM
5:59:38 PM
6:29:38 PM
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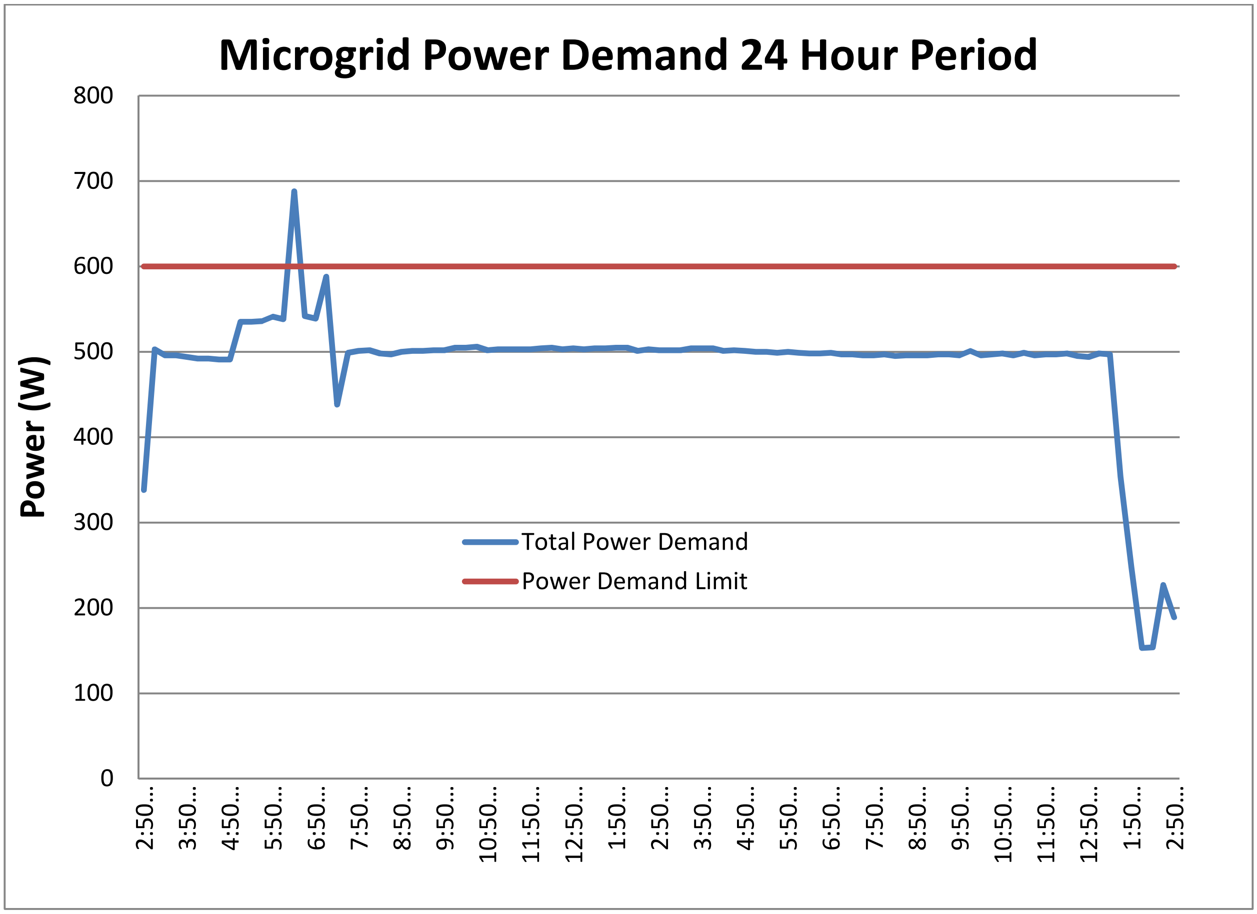
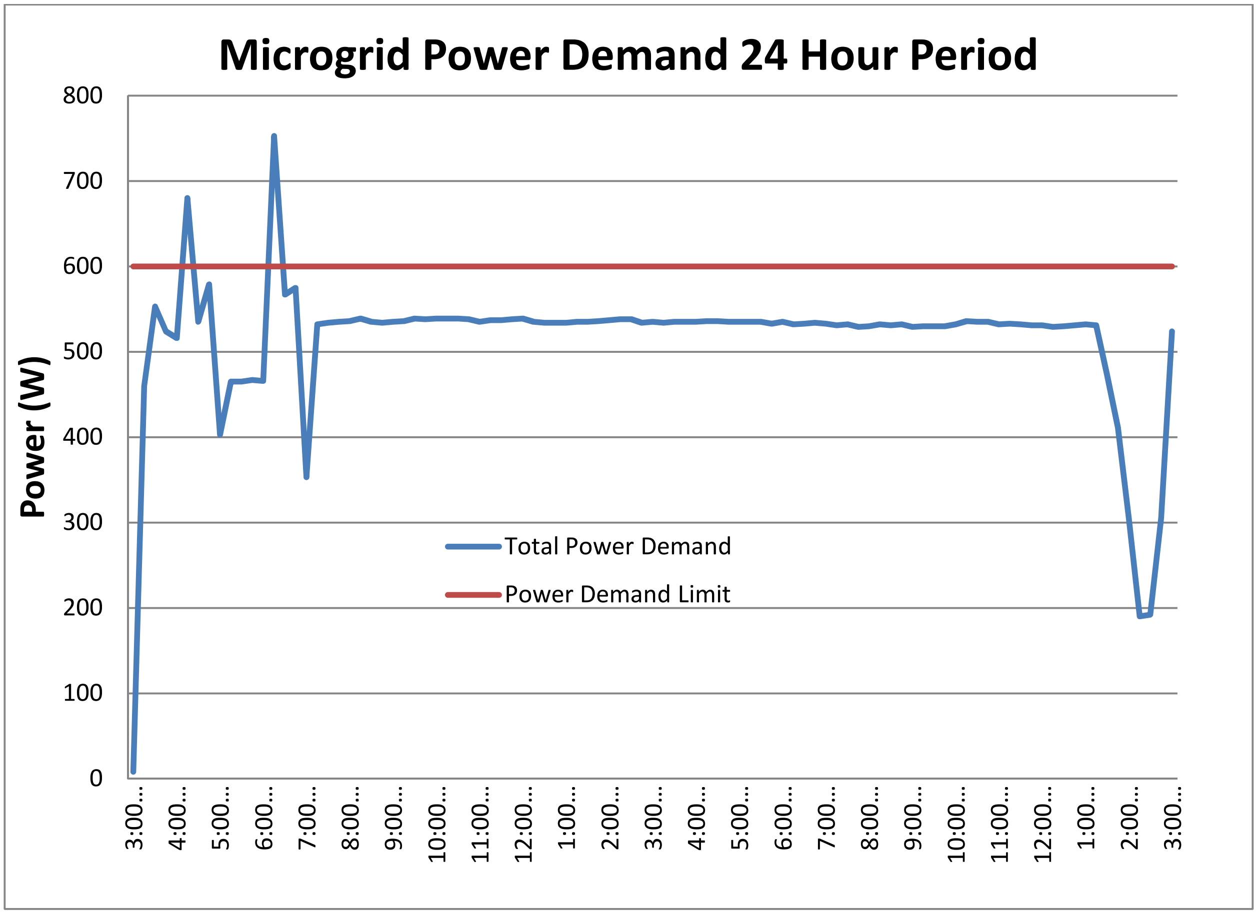
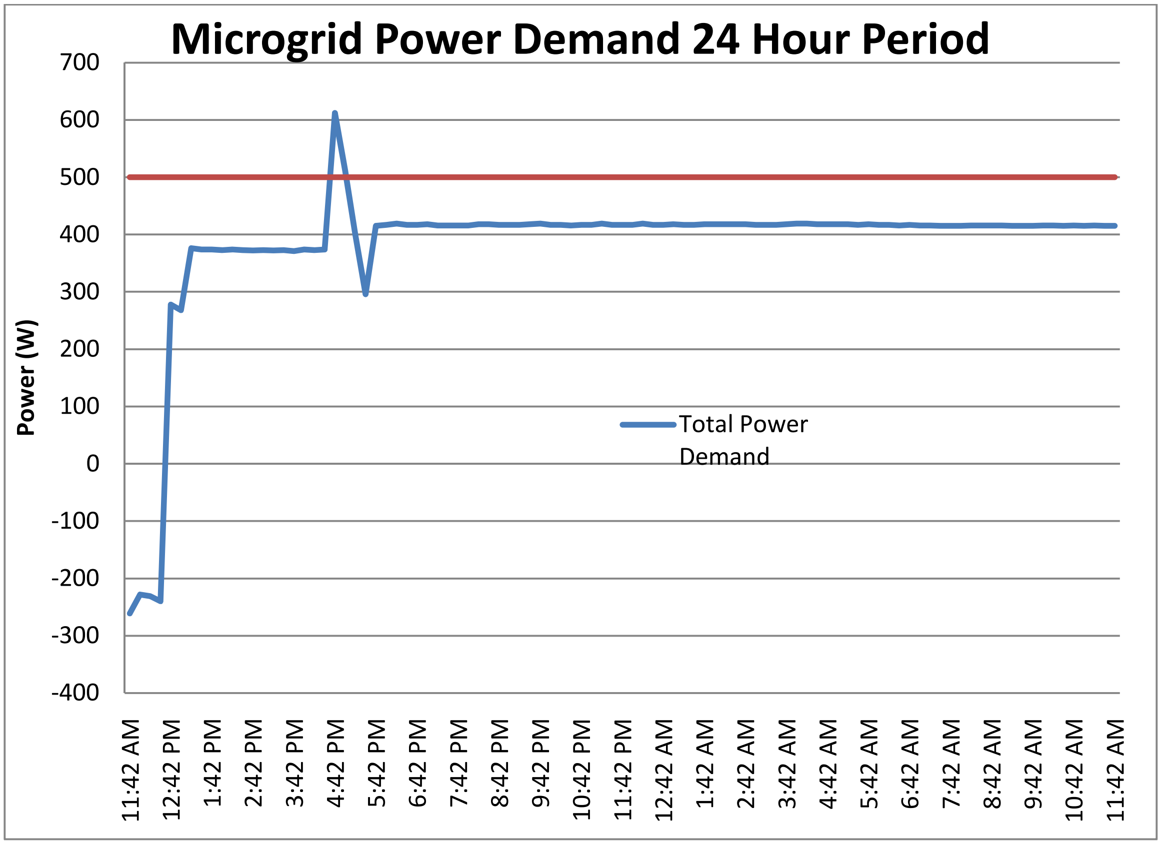
9:29:38 PM
9:59:38 PM



Microgrid Power Demand 24 Hour Period
Power (W)
800
700
600
500
400
300
200
100
0
Total Power Demand
Power Demand Limit
2:50...
3:50...
4:50...
5:50...
6:50...
7:50...
8:50...
9:50...
10:50...
11:50...
12:50...
1:50...
2:50...
3:50...
4:50...
5:50...
6:50...
7:50...
8:50...
9:50...
10:50...
11:50...
12:50...
1:50...
2:50...


Microgrid Power Demand 24 Hour Period
Power (W)
800
700
600
500
400
300
200
100
0
3:00...
4:00...
5:00...
6:00...
7:00...
8:00...
9:00...
10:00...
11:00...
12:00...
1:00...
2:00...
3:00...
4:00...
5:00...
6:00...
7:00...
8:00...
9:00...
10:00...
11:00...
12:00...
1:00...
2:00...
3:00...
Total Power Demand
Power Demand Limit


Microgrid Power Demand 24 Hour Period
Power (W)
700
600
500
400
300
200
100
0
-100
-200
-300
-400
Total Power Demand
11:42 AM
12:42 PM
1:42 PM
2:42 PM
3:42 PM
4:42 PM
5:42 PM
6:42 PM
7:42 PM
8:42 PM
9:42 PM
10:42 PM
11:42 PM
12:42 AM
1:42 AM
2:42 AM
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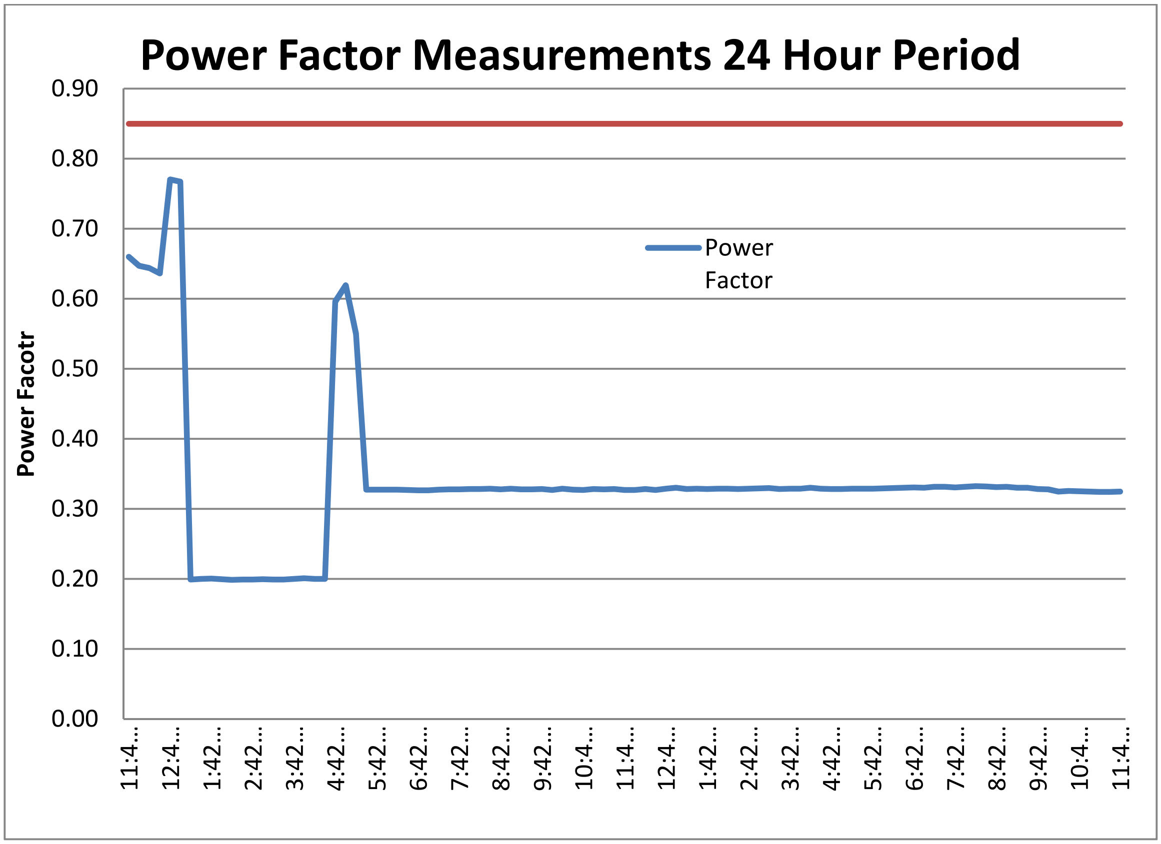
8:42 AM
9:42 AM
10:42 AM
11:42 AM



Power Factor Measurements 24 Hour Period
Power Facotr
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Power Factor
11:4...
12:4...
1:42...
2:42...
3:42...
4:42...
5:42...
6:42...
7:42...
8:42...
9:42...
10:4...
11:4...
12:4...
1:42...
2:42...
3:42...
4:42...
5:42...
6:42...
7:42...
8:42...
9:42...
10:4...
11:4...

APPENDIX D

APPENDIX D

POWER FACTOR DEFINITION AND CALCULATION

AC power flow has the three components: real power (also known as active power) (P), measured in watts (W); apparent power (S), measured in volt-amperes (VA); and reactive power (Q), measured in reactive volt-amperes (VAR). Their relationship can be expressed as

$$Q = \sqrt{S^2 - P^2}$$

That is

$$\text{Reactive Power} = \sqrt{(\text{apparent power})^2 - (\text{active power})^2}$$

The ratio of real power to apparent power is called power factor. The power factor is given by the following equation, and has the geometric interpretation given in Figure 1.

$$\text{PF} = \frac{\text{Active Power}}{\text{Apparent Power}} = \frac{P}{S} = cos\,\theta$$

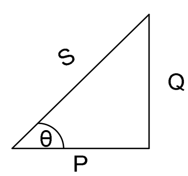


Figure 1: Power Triangle

The power factor is by definition a dimensionless number between 0 and 1. When power factor is equal to 0, the energy flow is entirely reactive, and stored energy in the load returns to the source on each cycle. When the power factor is 1, all the energy supplied by the source is consumed by the load. Power factors are usually stated as "leading" when the current leads voltage (capacitive load) and "lagging" means that the current lags the voltage (inductive load). This is used to show the sign of the phase angle.

The significance of power factor lies in the fact that utility companies supply customers with volt-amperes, but bill them for watts. Power factors below 1.0 require a utility to generate more than the minimum volt-amperes necessary to supply the real power (watts). This increases generation and transmission costs [32].

APPENDIX E

APPENDIX E

LABORATORY HANDOUT

LAB : Smart Micro Grid

A. OBJECTIVES

- Observe basic properties of a smart micro grid
- Observe properties of a demand controller circuit implementation
- Become familiar with power factor billing
- Measure power demand and generation

B. EQUIPMENT REQUIRED

- PM300 power analyzer
- Wound Rotor Induction Motor
- Prony brake
- Variable load (resistive and reactive)
- DC motor
- Variable AC and DC power supply
- NI ELVIS
- Miscellaneous Cables
- Breadboard

C. PARTS REQUIRED

- (3)Power opto-triac
- (3)200 ohm, 1/2W resistor
- Hook-up wire

D. PRIOR TO LAB

Demand Controller

An important aspect of the smart micro grid is to have self regulation capability. This provides the utility companies with a real time response to high demand peaks. In that sense the demand controlled load portion of the experimental setup is aiming at providing this important feature to the laboratory based micro grid.

The demand control setup consists of two main parts, one is the high priority load represented by the WRIM with a prony brake attachment; and the other is the low priority load represented by three 60W bulbs. The following **Figure 1** shows the system setup schematic. NOTE: there is only 1 opto- triac circuit and light bulb shown, but the experimental setup requires 3.

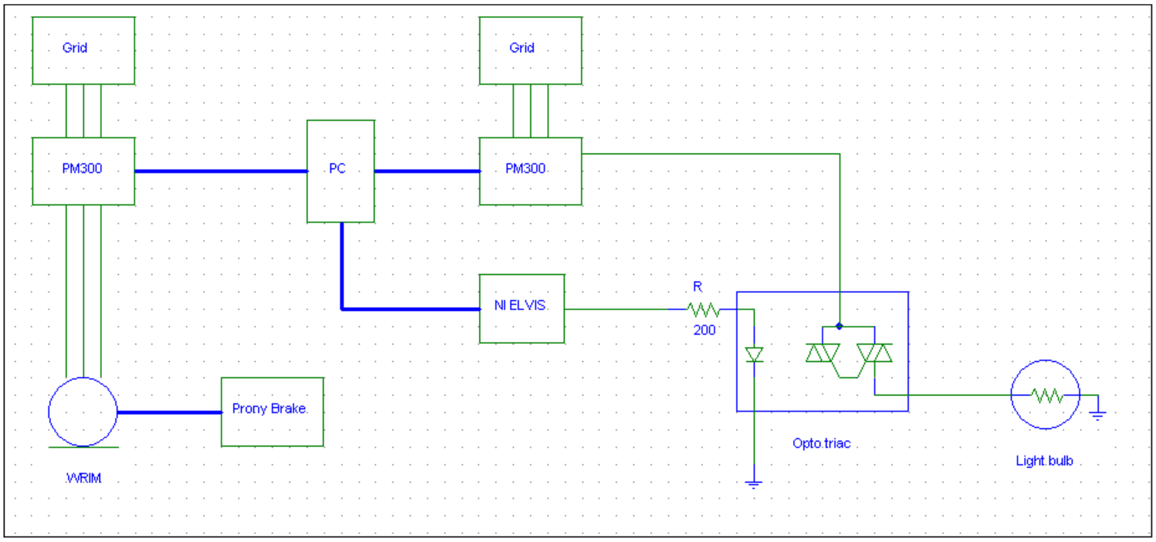


Figure 1: Demand Controller (1-phase)

Power Factor billing simulation

The purpose of this section is to implement the techniques used by the power companies to penalize business clients when their power factor is below a certain value.

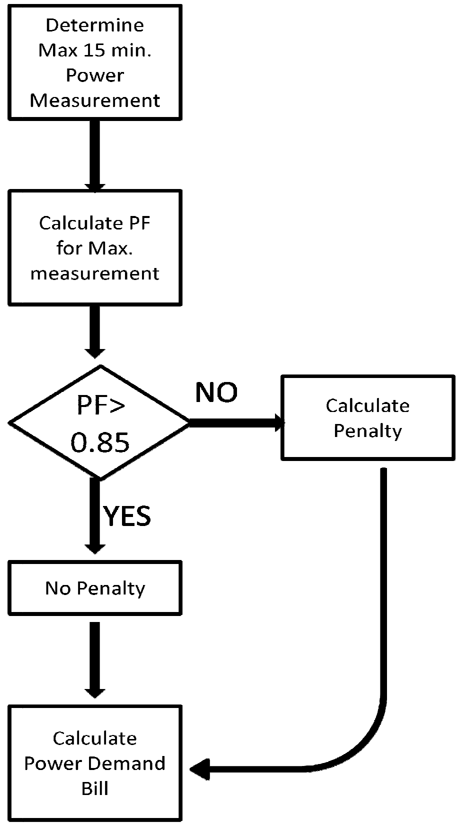


Figure 2: Billing method

Once the process is completed the penalty for power factor is determined and then the cost of the energy consumption is calculated using one of the following formulas:

With Power Factor Penalty:

Where "P.F." represents the power factor calculated for the maximum 15 minute KW measurement. The "Rate" variable represents the cost per KW.

Without Power Factor Penalty:

The system setup can be observed in the following figure. Note that the WRIM has both resistive and reactive loads. The values of the variable inductance and variable capacitance are recorded in the **Tables 1 and 2** below.

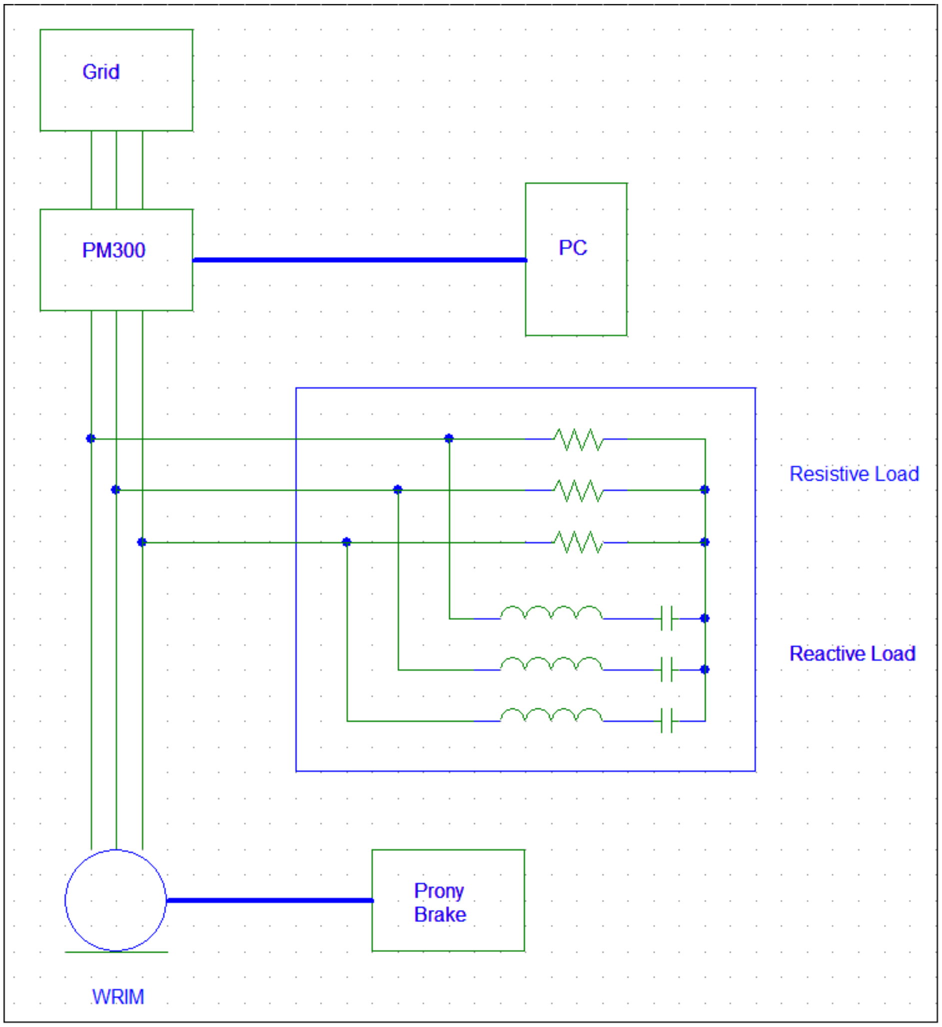


Figure 3: Schematic of WRIM with resistive and reactive loads

Table 1: Variable Inductance load values

Dial position (counterclockwise)	Inductance (Henry)
0	10.56
-1	9.88
-2	5.16
-3	2.71
-4	1.91
-5	1.43
-6	1.17
-7	0.97
-8	0.85
-9	0.74
-10	0.67
-11	0.57
-12	0.51
-13	0.47
-14	0.43
-15	0.41
-16	0.37
-17	0.35
-18	0.33

Table 2: Variable capacitance values

Dial position (clockwise)	Capacitance (μF)
0	0.69
1	1.57
2	3.16
3	5.01
4	6.4
5	8.06
6	9.85
7	11.6
8	13.6
9	16.09
10	18.23
11	20.07
12	21.7
13	25.13
14	28.6
15	30.9
16	32.69
17	35.69

Power generation and voltage monitoring

For this section of the experimental setup, a combination of WRIM and DC motors are used in order to obtain a generation point in the microgrid. This setup, shown in schematic form in **Figure 4** below, consists of two variable power supplies, both are capable of outputting AC and DC voltage and vary them thorough manual controls. This characteristic has been used in order to simulate a voltage drop through the phases

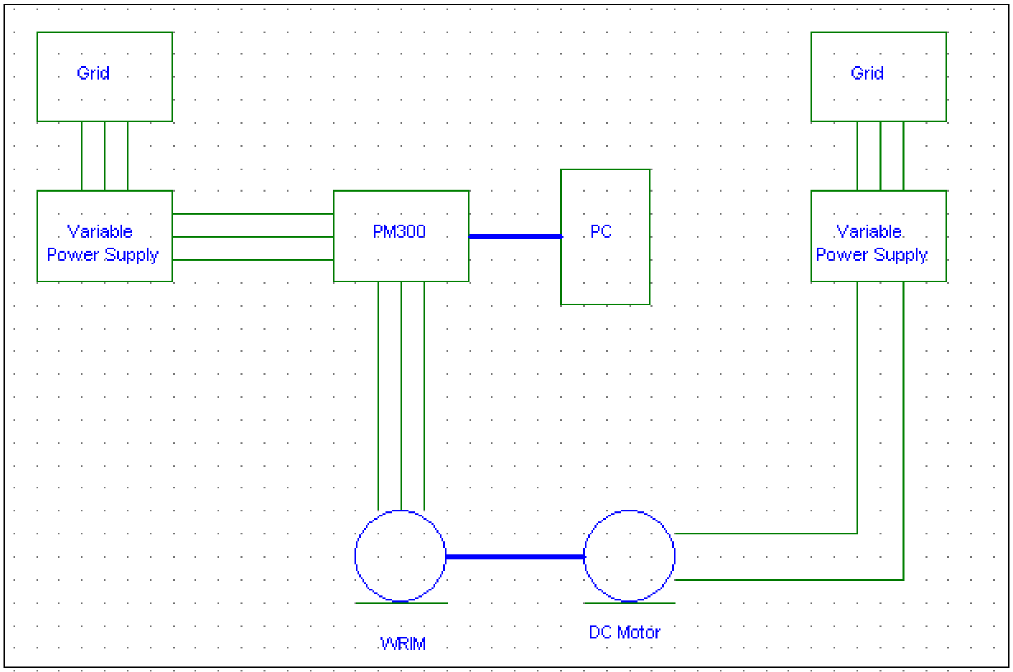


Figure 4:Schematic of generation point

E. IN THE LAB

(1)LabVIEW control setup: Fill out the portion labeled “Controls” in the front panel GUI of the Lab VIEW program. An example is shown below in **Figure 5**, use the values provided by your lab instructor.

NOTE: Keep in mind that Meter 1 will be the light bulbs, Meter 2 will be the generation point, and Meter 3 will be the WRIM with prony brake and variable resistance and reactive loads.

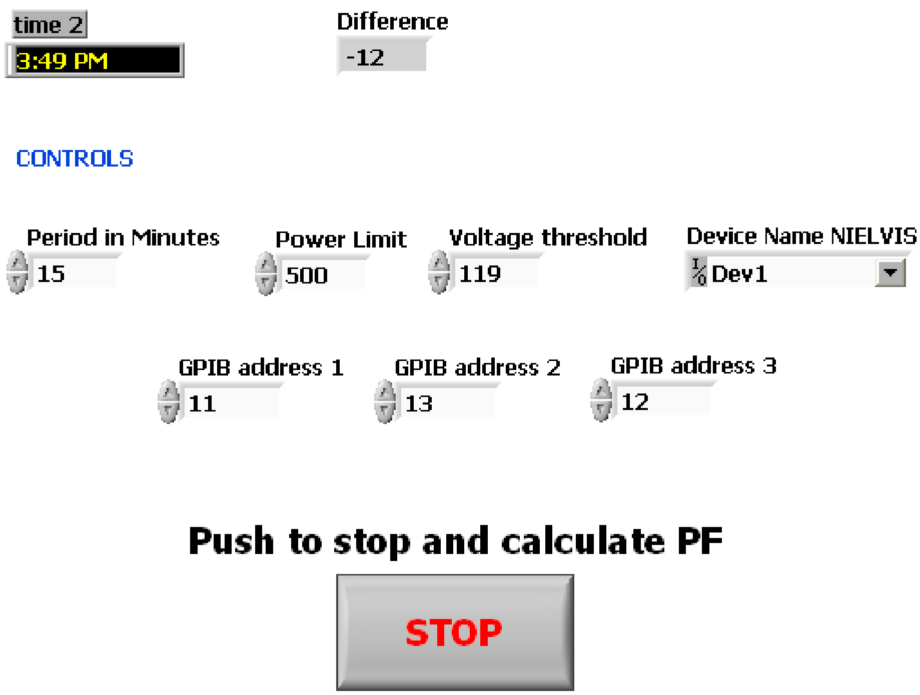


Figure 5: GUI controls

(2)Low voltage manipulation: using the variable power supply connected to the WRIM in the generator set up, slowly increase the voltage level, while you are doing this, you should observe that the virtual LEDs in the GUI are illuminated.

As you reach and surpass your voltage threshold, specified previously, you should observe the LEDs turn off, and will look like the ones shown in **Figure 6** below. Stop increasing the voltage when you have reached 120 V per phase.

Figure 6:virtual LED indicators

Include in your lab report a small paragraph explaining how this type of system represents an advantage for the power companies.

(3)Demand controller circuit: using the prony brake attached to the WRIM increase the power demand, which you can monitor on the GUI, by meter as well as the total microgrid load as shown in **Figure 7** below.

NOTE: you must monitor the power factor measurement simultaneously as you are varying the power demand; the procedure is explained in the next section (4).

Figure 7: Total power load measurement GUI

Once you surpass the power demand limit specified in the controls, you must record the total power demand value, as well as how many light bulbs are disconnected by the system. This will allow you to calculate how much the power demand will decrease, and what will be the next measurement for total power load. Repeat the process for all three scenarios of disconnect, meaning 1,2,and 3 light bulbs disconnected. Record your measurements and calculations in the table below.

Total power load	Number of Light bulbs disconnected	Next calculated power load	Next measured power load

The next phase requires that you engage the generator. This will be done by varying the voltage provided by the variable power supply connected to the DC motor, this will allow the WRIM’s speed to achieve and surpass its synchronous speed, thus it will start to generate power and inject it into the grid.

As you perform this, you will notice that the light bulbs that were disconnected will start to reconnect as you generate more power for the microgrid. Record the following measurements as shown in the table below.

Total Power load	Power from generator	Number of Light bulbs on

In your lab report provide a brief explanation as to how this system could be translated into an everyday home or business, and what benefits would derive from it.

(4)Power Factor:

As you are varying the power demand, you must monitor the power factor measurement shown in the PM300, meter 3. Make sure you are recording the energy consumption (Wh) from this meter at each iteration of the run.

Once you have reached the maximum power demand, you must adjust the variable resistances and capacitance values in order to increase the power factor above the specified level (0.85).

When the trial is near its end, push the “STOP” button in the program and after the last iteration, the program will calculate the energy consumed measured in meter 3, it will show the power factor of the peak demand, it will indicate if there was a penalty and it will calculate the cost.

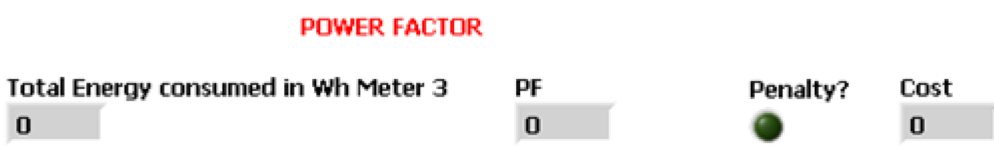


Figure 8: Power Factor section of the GUI

Using the measurements of energy consumption you recorded for each iteration, calculate a total, and using the formula for no penalty provided in the “Before the lab” section, calculate the cost using a price of $0.13 per KWh. Then compare your calculations to the ones provided by the program.

F. AFTER THE LAB

Answer the following questions regarding power factor:

1-Did the increase/decrease in reactive load affect the apparent power radings (watts)? YES/NO

Why?

2-Why is it important for power distribution companies to monitor power factor, and how does a lower power factor affect the end user?

Using the output file create the following plots:

1-A plot containing time vs. total power demand

2-A plot containing time vs. power factor

References:

LabVIEW: file is contained in directory My Documents/Smart Micro grid/All together

Filename: All_3_together.vi

BIOGRAPHICAL SKETCH

Jose Luis Sanchez was born in Reynosa, Mexico on May 3rd 1986. A keen aptitude to mathematics inherited from his mother, and a creativity to solve problems shared with his father encouraged Jose to pursue a degree in the engineering field.

He came to the United States on August 2004 and enrolled in the University of Texas Pan American with the goal of challenging himself and seeking an undergraduate degree from the electrical engineering program. After four years, in which he participated in events such as the IEEE region V Robotics competition, he graduated in the spring of 2008.

Upon completion of his undergraduate degree he enrolled in the graduate program of electrical engineering, and his first summer in the program began working with Dr. Jaime Ramos in the Power Systems Lab, this sparked his interest of power systems and renewable energy, and began pursuing a thesis work regarding this field. His current interests include power systems and smart grid technology as well as renewable energy. His permanent address is 12112 Stoney Meadow Dr., in Del Valle TX, 78617.