Educational Approach to the Methodology of Implementing Wireless Control of Power Flow in Hybrid Power Systems

Mr. Tan Ma, Florida International University

Tan Ma (S'09) received the M. Eng. degree in control theory and control Engineering from Huazhong University of Science and Technology (HUST) in China in 2009 and the Bachelor of Eng. degree in automation from HUST in China in 2007. He is currently pursuing his doctoral degree in electrical engineering at Florida International University. His research interests include Power System Operations and Control, Artificial Intelligence Applications to Power Systems, Energy Conservation and Alternate Energy Sources and smart grid power system design and optimization.
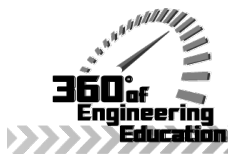
Prof. Osama A. Mohammed, Florida International University

Dr. Mohammed is a Professor of Electrical Engineering and is the Director of the Energy Systems Research Laboratory at Florida International University, Miami, Florida. He received his Master and Doctoral degrees in Electrical Engineering from Virginia Tech in 1981 and 1983, respectively. He has performed research on various topics in power and energy systems in addition to computational electro-magnetics and design optimization in electric machines, electric drive systems and other low frequency environments. He performed multiple research projects for several Federal agencies since 1990's dealing with; power system analysis, physics based modeling, electromagnetic signature, sensorless control, electric machinery, high frequency switching, electromagnetic Interference and ship power systems modeling and analysis. Professor Mohammed has currently active research programs in a number of these areas funded by DoD, the US Department of Energy and several industries. Professor Mohammed is a world renowned leader in electrical energy systems and optimization techniques. He has published more than 350 articles in refereed journals and other IEEE refereed International conference records with nearly a 130 journal articles. Professor Mohammed is an elected Fellow of IEEE and is an elected Fellow of the Applied Computational Electromagnetic Society. Professor Mohammed is the recipient of the prestigious IEEE Power and Energy Society Cyril Veinott electromechanical energy conversion award and the 2012 outstanding research award from Florida International University. He is the author of book chapters including; Chapter 8 on direct current machines in the Standard Handbook for Electrical Engineers several in editions including the 16th Edition, McGraw-Hill, 2007 and 2012. He is also the author of a book Chapter entitled " Optimal Design of Magnetostatic Devices: the genetic Algorithm Approach and System Optimization Strategies," in the Book entitled: Electromagnetic Optimization by Genetic Algorithms, John Wiley & Sons, 1999. Professor Mohammed has lectured extensively worldwide in invited and plenary talks at major research and industrial organizations worldwide and International conferences. He serves as editor of several IEEE Transactions including the IEEE Transactions on Energy Conversion, the IEEE Transactions on Smart Grid, IEEE Transactions on Magnetics, IEEE Transactions on Industry Application and COMPEL. Professor Mohammed has served as the International Steering Committee Chair for the IEEE International Electric Machines and Drives Conference (IEMDC) and the IEEE Conference on Electromagnetic Field Computation (CEFC). He has been general chair of six major international conferences in power and energy, computational electromagnetics and intelligent systems over the past 20 years. He also serves as chairman, officer or as an active member on several IEEE Power and Energy Society committees, sub-committees and technical working groups. He a past member of the IEEE Power and Energy Society Governing Board and a past member of the Florida Power and Light Company Consumer Advisory Board.

For resume and complete list of publications, the following link has all the details; http://www.energy.fiu.edu/contact/

Brandy Louie Serrano, Florida International University

Brandy Louie Serrano was born in 1989. He received his Bachelor's degree in electrical engineering from Florida International University in Miami, FL in 2013. He is currently working as an undergraduate research assistant at Florida International University's Energy Systems Research Laboratory. He has

assisted in various power systems research topics focusing on hybrid electric vehicle integration in the utility grid, battery management systems, and control of power flow in hybrid AC-DC systems.

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also serves as chairman, officer or as an active member on several IEEE PES committees, sub-committees and technical working groups.

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Abstract

Abstract— In this paper, the methodology of utilizing microcontrollers and transceivers to wirelessly control the power flow in a hybrid AC-DC power system through multiple bidirectional DC-DC and AC-DC converters in real-time is presented. The various steps involved in this process teach the student numerous engineering concepts in power electronics, microcontrollers, software tools, and wireless communications. This hands-on approach introduces numerous concepts and software tools to the undergraduate engineering student and thoroughly engages the student in these concepts. The various steps involved in developing this type of wireless control will be outlined with illustrations. All of the various hardware configurations along with the software utilization will also be demonstrated in detail. In this presented design, Matlab Simulink and TeraTerm Pro are used in conjunction with the STM-32F Discovery microcontroller and XBEE transceivers. The end result of this design is to allow the student to wirelessly control the duty cycle of the pulse width modulated signals that control the switching devices of DC-DC and AC-DC converters to regulate the power flow in the proposed hybrid AC-DC power system. The proposed methodology has future applications in hybrid micro grids to allow efficient and reliable coordination of power flow.

Educational aspects:

The presented utilization of microcontrollers and transceivers in the wireless control of DC-DC and AC-DC converters encompasses several educational aspects such as:

Comprehensive instruction in wireless communications between devices

- The process of creating wireless communications between the XBEE transceivers and microcontrollers to send a user controlled duty cycle is explained thoroughly and can be observed on an oscilloscope.

The process involved in building Simulink models that allow for user controlled power flow

- A detailed description of all the library blocks used in Matlab Simulink and their parameters is presented. Specific libraries allow the student to communicate with the TeraTerm Pro software, the terminal used by the student to vary the duty cycle of specific converters.

The direct application to hybrid micro grids is also presented to teach the student the coordination and control of power flow in micro grids

- The hybrid micro grid detailed in this paper represents a plug-in electric vehicles (PEVs) charging parking lot that connects to the main utility through a common DC bus. The vehicles are represented by batteries which can either receive energy from the grid to charge themselves or absorb/inject active and reactive power into the grid.

I. Introduction

The implementation of microgrids (MG), along with the utilization of plug-in hybrid electric vehicles (PHEV) are growing in popularity, increasing the demand for efficient and reliable power flow control systems that can monitor and regulate power flow in hybrid AC-DC power systems [1]-[2]. Control of power flow in hybrid AC-DC power systems is done by controlling the multiple bidirectional DC-DC and AC-DC converters used in these grids [3]-[4]. It is of the utmost importance to teach power systems engineering students how to communicate with devices, such as converters and battery management systems, to monitor and control the power flow across a micro grid [5]. The growing implementation of smart grids and wireless communications emphasizes the need to teach students how to implement wireless communication devices with applications to power flow control.

In this paper, the methodology of utilizing microcontrollers and transceivers to wirelessly transmit a pulse width modulated signal with variable duty cycle to control power flow through different converters in a hybrid AC-DC power system will be presented. The configuration of the hybrid MG can be shown in Figure 1. Matlab Simulink and TeraTerm Pro [6] are used in conjunction with the STM-32F Discovery microcontroller and XBEE transceivers [7]. Matlab Simulink is used to design and embed code using the Waijung library block set [8]. This library of components allows the student to
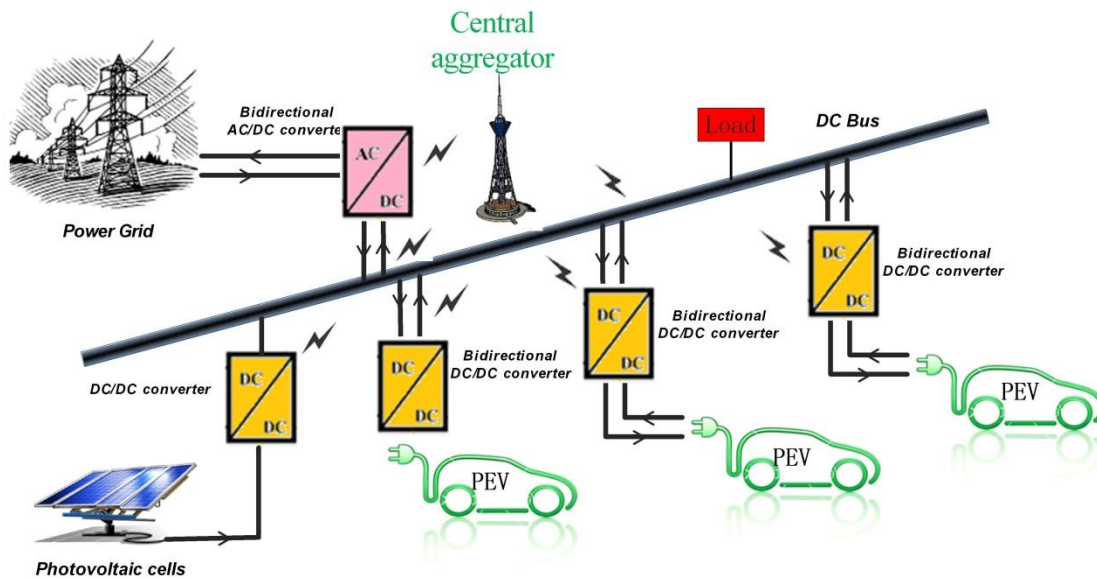

Fig. 1 Abstract diagram of the hybrid AC/DC system with wireless control

communicate with the microcontroller to build designs into it once the Matlab Simulink model is completed. Instead of directly connecting the microcontroller to the computer, XBEE Series 1 transceivers are used to transmit data to the board. This is done with the software X-CTU which allows the student to modify all the parameters of each transceiver module to allow for a mesh communication between devices. These modules are then directly connected to the microcontroller(s) to complete the transfer of data from user to microcontroller(s).

This methodology is presented to the student as a hands-on engineering solution to the need for a plug-in electric vehicle parking lot that serves to charge and discharge the battery of each vehicle through a bidirectional DC-DC buck-boost converter while it is parked. This vehicle parking lot can be directly connected to the AC utility grid through a bidirectional AC-DC converter to not only charge vehicles, but to serve as an energy storage device to increase the stability of the utility grid by supplying additional power during high demand.

The paper is organized as follows; wireless communication between XBEE transceivers using the software X-CTU and TeraTerm Pro is detailed in Section II. Section III presents the hardware aspects of this design. Section IV details the process of using Matlab Simulink to control the duty cycle of the pulse width modulated signals produced from the microcontrollers. Conclusions are drawn in Section V.

II. Wireless Communication Using XBEE transceivers

The first step in the process is to acquire the appropriate number of microcontrollers, transceivers, XBEE adapters, and one XBEE Explorer interface board with a USB cable. Then, the student must download and update X-CTU, TeraTerm Pro, and the Waijung Library to use in Matlab Simulink. The TeraTerm Pro is used to transfer data between transceivers while the X-CTU is used configure the communication between them. After the installation process, the parameters can be altered. The steps to change parameters are detailed and illustrated below.

X-CTU: When the student opens this program, they are presented with the following tab, shown in Figure 2.

Be sure to open the program after the student has plugged a transceiver on to the interface board and then connect the board on to the computer via USB. The specific port used will then show up on the ports list. As can be seen, the transceiver is currently connected to COM2. The student can verify which port is used by the transceiver by going to device manager from the control panel in your Windows machine and looking at the port designations. The Baud rate refers to the speed data is to be transferred. Flow control manages the rate of data to prevent data overflow or dropped packets of information. The Data Bits, Parity, and Stop Bits are rarely altered and should remain the same for this

process. Once these default parameters are verified, click Test/Query. The student should be presented with a small window that verifies the connection of your XBEE module.
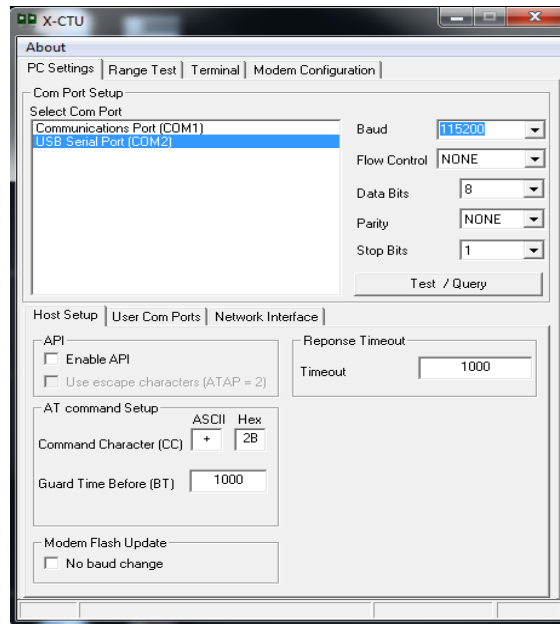

Fig. 2: X-CTU Program

Then, click on the Modem Configuration tab. The student will be presented with the following image, shown in Figure 3.
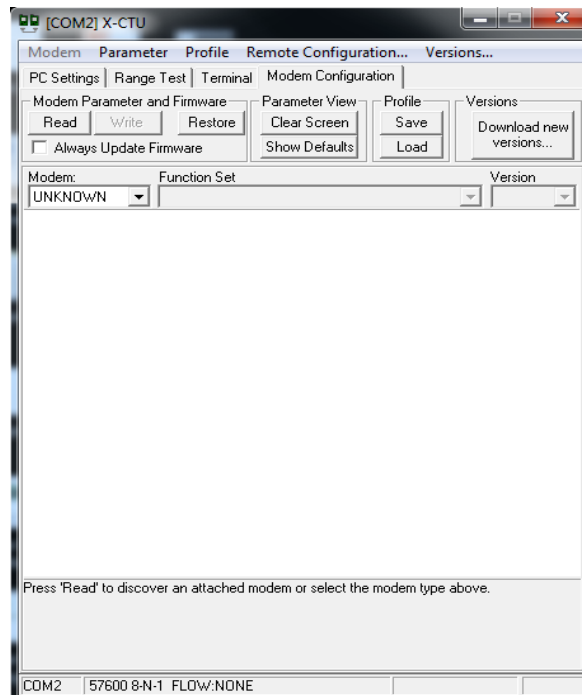

Fig. 3: X-CTU Configuration

Once on this tab, click Read. After a few seconds the student should be presented with the following image. Here are all the parameters that are on your module. The only ones of importance for the time being are Channel, PAN ID, and Interface Data Rate (Baud Rate) which are usually colored blue. In order to have the proper mesh communication between all of the XBEE modules, these three parameters have to be identical. The Matlab Simulink design and TeraTerm Pro software must also use the same Baud rate. The student can view all the possibilities of these parameters on the XBEE Series 1 data sheet found online. In general, the student should use the letter B or C for the Channel and then a combination of four numbers for the PAN ID. You should verify that this specific combination is not being used by any other student to avoid communicating with their modules. In general, the XBEE modules work best using the Baud Rate 57600. They work on any Baud Rate listed but it is recommended to use them at 57600. Once the appropriate values for these three parameters have been chosen, click Write. Repeat this process for all of the modules.
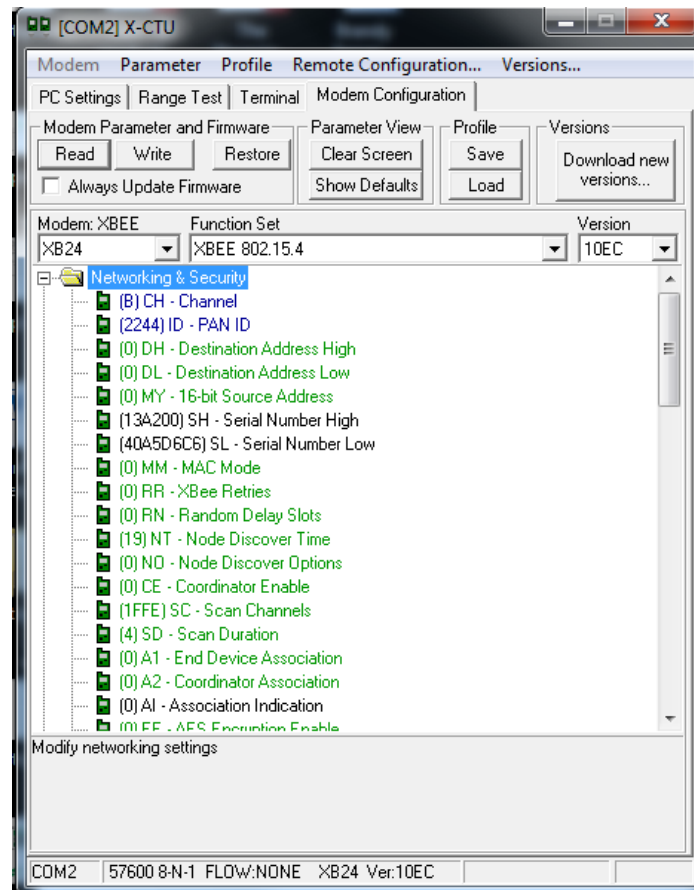

Fig. 4: X-CTU Parameters

Once this step is complete, the student can move on to configure TeraTerm Pro. TeraTerm Pro is a terminal emulator that emulates a variety of different computer terminals and supports internet communications such as telnet and SSH and also allows

serial communications which is what is used in this procedure. When opening TeraTerm Pro, the student is presented with the following image, shown in Figure 5:
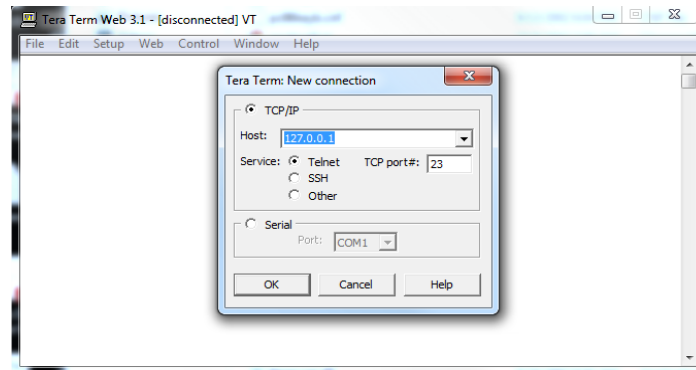

Fig. 5: TeraTerm Software

At this point, the student will click serial and choose the same port as the XBEE interface board from before and press OK. Now, click Setup and then Terminal. Alter the settings to the following, shown in Figure 6:
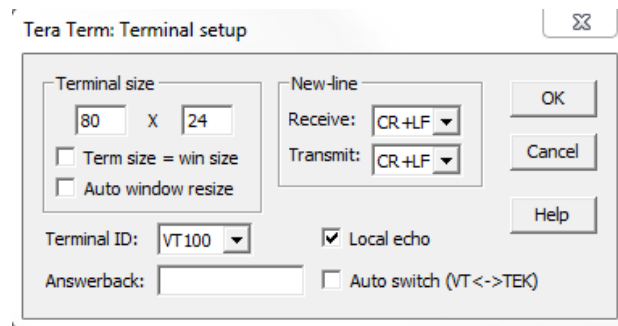

Fig. 6: TeraTerm Setup

Now, click Setup again and go to Serial Port. Verify that all of the parameters are identical to the ones used in the experiment. In general, all the student should have to alter is the Baud Rate to the one being used. The student is now presented with a clear console that is ready for input commands that are sent to the microcontroller to generate the pulse width modulated signal with a user controlled duty cycle.

III. Implementation of Microcontrollers

The next step is to properly connect the transceivers to the microcontrollers using the XBEE Explorer adapters. Place the transceiver on an adapter and using four of the thin spiral colored cables, connect the following pins together;

- o Pin GND of the adapter to any GND of the microcontroller
- o Pin 5V of the adapter to Pin 5V of the microcontroller
- o Pin RX (receive data) of the adapter to Pin B6 of the microcontroller

    o   Pin TX (transfer data) of the adapter to B7 of the microcontroller

Repeat the process for the appropriate number of microcontrollers the student wishes to use. In this process, five microcontrollers were used to generate five different pulse width modulated signals with variable duty cycles. The student should then provide power to each microcontroller. This can be done in one of two ways; directly connect the microcontroller to the computer via USB or connect the other Pin 5V to the positive terminal of a power supply and a GND Pin to the negative terminal of the power supply. Before connecting, adjust the power supply to a constant 5V. To connect multiple microcontrollers to the power supply, use a breadboard to connect the 5V pins and GND pins in parallel with the power supply.

IV. Matlab Simulink Design

At this point, all that is left is the Matlab Simulink design using the Waijung library block sets. The design built into each board that generates multiple pulse width modulated signals with variable duty cycles is seen below:
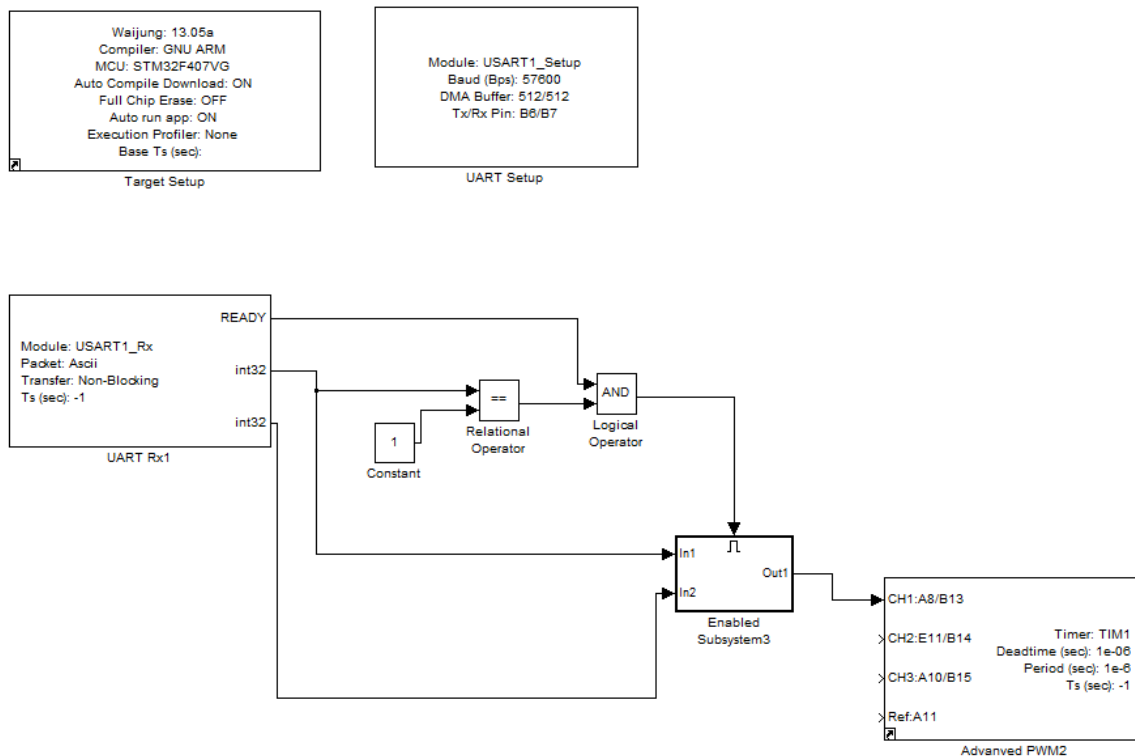

Fig. 7: Matlab Simulink Design

All of these blocks are found in the library browser under Waijung Block sets. The Target Setup block is added to all designs that utilize the STM-32F microcontrollers and allows for the design to be properly built into the board. There are no settings that need to be altered from the default block. The UART Setup block is where the communication

parameters are altered. This block is also where the pins used for communication are located on the microcontroller. Be sure to select Module 1 as well. The image below shows the parameters and the parameters should already be familiar to the student:
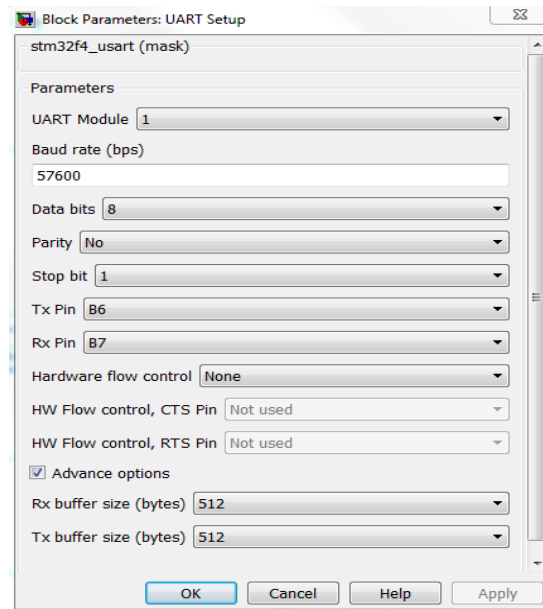

Fig. 8: Matlab Simulink Flow Control

The UART Rx1 Block is the block that allows the student to communicate directly with the microcontroller of choice and its respective duty cycle. Below is an image showing its parameters:
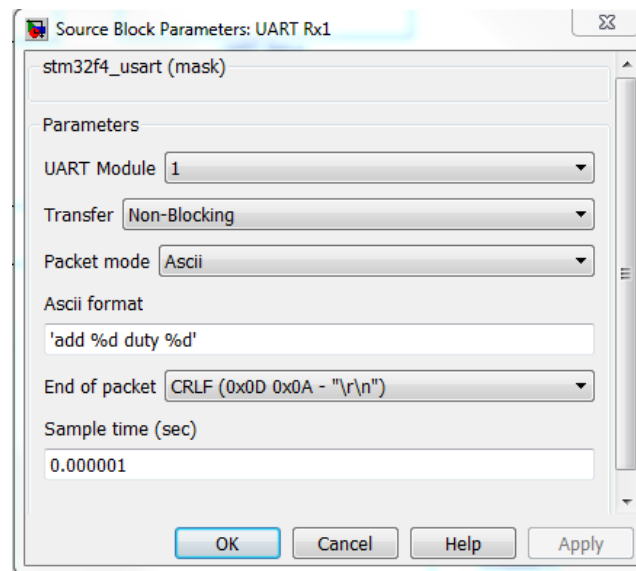

Fig. 9: Matlab Simulink Parameters

As can be seen, the UART module is the same as before. The transfer of data is chosen as Non-Blocking. With this option, we can enter new data without blocking any current procedure being carried out. This allows the student to change duty cycles in real time when other duty cycles are present. The packets of data are sent as ASCII characters. The line 'add %d duty %d' is what the student inputs into the TeraTerm Pro terminal. Each board has a specific address. Since this design has five microcontrollers, there are five different options. The following example illustrates how the line is used:

'add 1 duty 56'

In this line, the student wants board 1 to generate a pulse width modulated signal with a duty cycle of 56 percent.

In this design, the address is sent to a relational operator that compares it to an integer. This integer refers to the address of a specific board with each board having the exact same design built into it with the exception of this constant. Board 1 will have the number 1 in this box. Board 2 will have the number 2 in this box, etc. If the user typed the same number for address as the constant, then the AND gate will register as 1 and the Subsystem will be enabled, allowing the duty cycle to pass through to the board. That address number along with the duty cycle is sent into this subsystem where the output is then sent to the Advanced PWM block. The output of this PWM is located on Pin A8 to GND. Below is an image showing the subsystem:
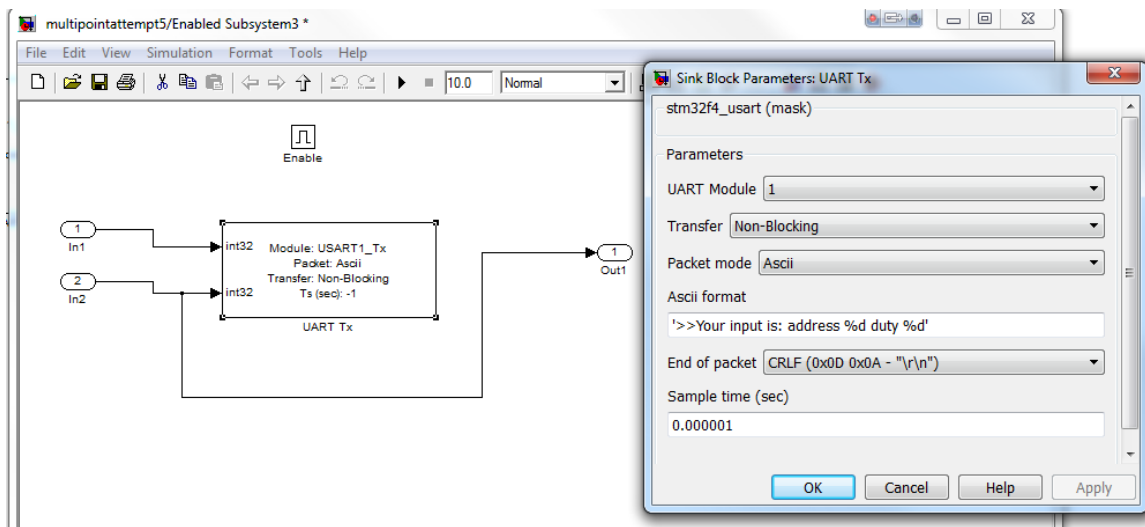

Fig. 10: Matlab Simulink Parameters

In Figure 10 it is observed that the address (In1) and duty cycle (In2) enter the transfer module so that the student receives a message in the terminal of what he/she inputted. In the above example, the output would be:

>>Your input is: address 1 duty 56

Also, observe that the duty cycle (ln2) is then outputted from the subsystem to Out1. This output is what reaches the PWM block. Once the design is complete and verified, click CTRL+B to build this design into the microcontroller. Remember to change the constant for each microcontroller. Since this design uses five boards, there are five slightly different builds. Board 1 gets the build with 1 as the constant. Board 2 gets the build with 2 as the constant, etc. The overall design should resemble the following:
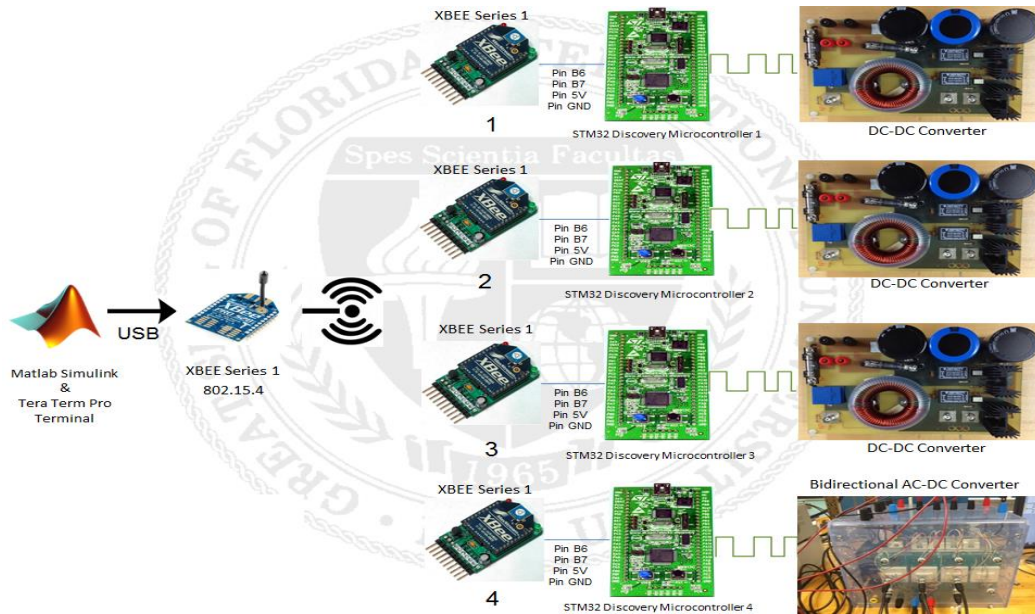

Fig. 11: System Hardware Design

In this design, the PWM's are used to control the switching frequencies of the IGBT's in converters to control power flow. It should be noted that before compiling the design in
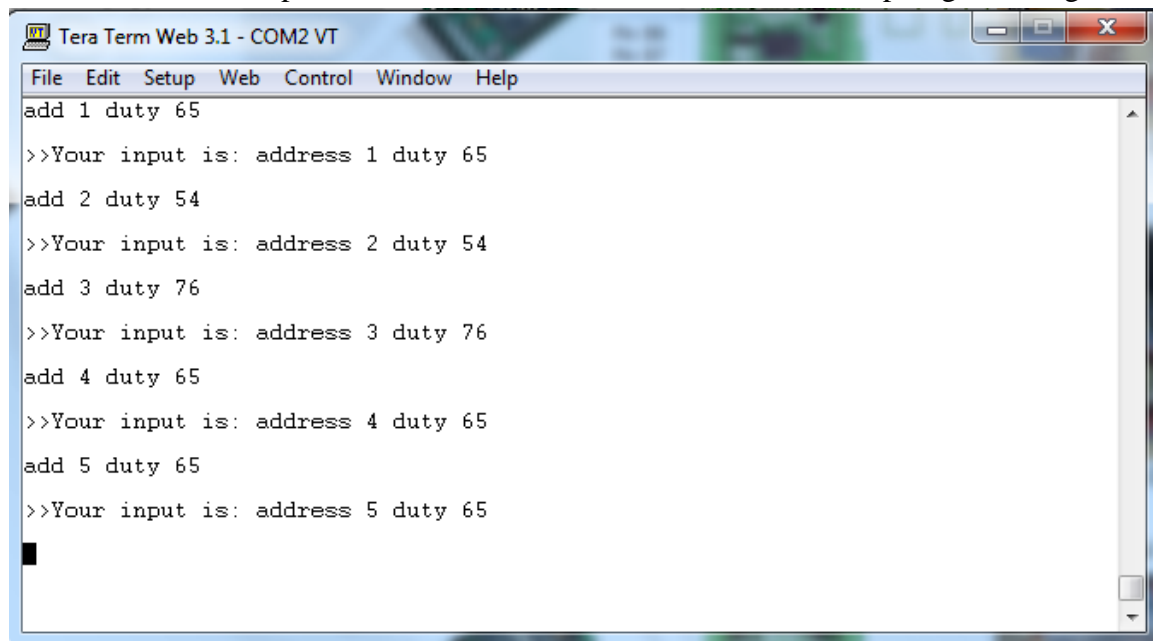

Fig. 12: TeraTerm User Terminal

the microcontroller, disconnect it from any power supply or modules. The only connection should be a USB cable that connects to the computer. Once all boards have been compiled appropriately, connect as above. Now, the student is ready to actually use the TeraTerm Pro program to control the duty cycles of multiple PWMs simultaneously. Figure 12 shows an image of the terminal being used to control five pulse width modulated signals:

V. Conclusion

This paper describes the methodology of using transceivers and microcontrollers to wirelessly control power flow in a hybrid AC-DC power system. The methodology encompasses numerous educational aspects that teach the undergraduate student a myriad of engineering concepts, all essential to his/her success as an engineer. Upon completing this methodology with the instructor, the student will have been introduced to power electronics concepts such as microgrids, plug-in electric vehicles, power flow, and devices such as bidirectional converters. The student has also familiarized themselves with the fundamentals of Matlab Simulink and has gained a greater understanding of microcontrollers and how they can be utilized to control power electronics devices on a basic level. The student should be able to reflect on all of these new and interesting engineering concepts in a very positive light since they were able to apply it themselves to a real world problem that will be prevalent in the foreseeable future with the continuous growth in electric vehicles and hybrid microgrids implementing energy storage devices.

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