

Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.

Smart Power Monitoring Utility System Using Wireless Sensor Networks

A Project Report

Submitted in partial fulfilment of the
requirements for the Degree of

Master of Engineering

In

ELECTRONICS AND ELECTRICAL ENGINEERING

By

Satinder Pal Singh Gill

Massey ID: 11187331



SCHOOL OF ENGINEERING AND ADVANCE TECHNOLOGY

MASSEY UNIVERSITY

PALMERSTON NORTH

NEW ZEALAND

May 2013

To my family

ABSTRACT

The design and development of a Wireless Sensor Networks based Smart Grid for home utility system for power utility has been presented in this thesis. The system utilises wireless power monitoring devices and control units. The electronic wireless power monitoring devices have been designed to monitor electrical parameters such as voltage, current and power of the household appliances. The measured electrical parameters are transmitted to a central controller via the ZigBee node. The central coordinator has been configured around a laptop computer and receives all the transmitted data from different nodes. The computer stores the measured data and analyses them. The computer is also connected to internet and the website of the electrical power supply company is accessed. The real-time electricity tariff is available to the controller. Based on the tariff condition the controller can determine the off-peak and peak-electricity rate. The controller can decide to switch off the unimportant electrical loads at peak-tariff situation. This is implemented by sending the necessary command to the zigbee node connected to the appropriate load. The zigbee node can then switch off the load by sending an off-command to the triac which is used as the control device. The user has the options of controlling the electrical appliances in different modes. If the users would like to continue the load to be on during the peak-tariff condition, the option of a manual switch can be used to bypass the triac. The appropriate electrical loads can be monitored as well as controlled using the developed GUI available at the laptop. The complete information of the system is also available through a website and appropriate control action can be implemented through a secured access. The objective of the research is to lower the consumption of power during the peak-tariff condition and thereby saves electricity cost. A prototype has been designed, developed and extensively tested. This Thesis presents the current work, experimental results and concludes with possible future research opportunities.

ACKNOWLEDGEMENTS

I take this opportunity to express my profound gratitude and deep regards to my Supervisor Professor Dr Subhas Mukhopadhyay for his exemplary guidance, monitoring, technical feedback and constant encouragement throughout the course of this project. The invaluable suggestions, guidance and constructive criticism from time to time shall carry me a long way in the journey of life on which I am about to embark. Professor Subhas has inspired me to become an independent researcher and helped me realize the power of critical reasoning. Without his help, this work would not have been possible.

I would like to acknowledge the efforts and thanks to Colin Plaw, Bruce Collins, Anthony Wade and Ian Thomas. I would like to thank the SEAT IT support staff for providing me with required IT tools to run software for my study.

I would also like to thank Nagender Suryadevara, Ph.D. Student at Massey University, whose work on development of the GUI, using wireless communication, has been very useful for this project.

I wish to acknowledge Peter Howarth for his careful reading of an early draft of the project thesis.

I would like to thank my friends; Parminder, Sandeep, Jas, Anthony and Mike for late nights at Labs and all my well-wishers, who love me and care for me.

I would like to express my gratitude to my parents and family for the unconditional emotional support throughout my time at university. Thank you for all the sacrifices you have made to give me a better chance in life.

Table of Contents

ABSTRACT	iv
ACKNOWLEDGEMENTS	v
CONTENTS	viii
LIST OF FIGURES	x
LIST OF TABLES	xi
LIST OF GRAPHS	xi
CHAPTER 1:INTRODUCTION	2
1.1 SMART GRID UTILITY SYSTEM	3
1.2 DESCRIPTION OF PROBLEM DOMAIN	5
ELECTRICITY HISTORY	5
1.3 AIM AND SCOPE OF RESEARCH	7
<i>1.3.1 Smart Grid utility system</i>	7
1.4 RESEARCH OBJECTIVES	9
1.5 OUTLINE OF THE THESIS	9
CHAPTER 2:LITERATURE REVIEW	12
2.1 EXISTING RESEARCH/ THE SOLUTIONS	13
2.2 ELECTRICAL PARAMETERS MEASUREMENT: EXISTING TECHNIQUES	19
2.3 CONCLUSION	21
CHAPTER3:WIRELESS TECHNOLOGIES for SYSTEM SET-UP and THE COMPARISON	24
3.1 INTRODUCTION	25
<i>3.1.1 Bluetooth wireless technology (IEEE 802.15.1)</i>	25
<i>3.1.2 Wi-Fi (802.11)</i>	26
<i>3.1.3 WiMAX (802.16)</i>	27
<i>3.1.4 ZigBee (802.15.4)</i>	28
3.2 COMPARISON OF ZIGBEE, WiFi AND BLUETOOTH	28
3.3 ZIGBEE	30
3.4 XBEE CONFIGURATION	31
<i>3.4.1 Configuration of the Coordinator</i>	32

3.4.2	<i>Configuration of the End Device</i>	33
3.4.3	<i>Software and Algorithm for XBee Data Reception</i>	36
3.5	ZIGBEE FEASIBILITY	38
3.6	CONCLUSION	40
CHAPTER 4: MEASUREMENT OF PARAMETERS		42
4.1	INTRODUCTION	43
4.2	SYSTEM SET UP	43
4.3	VOLTAGE MEASUREMENT	47
4.4	CURRENT MEASUREMENT	49
4.5	POWER FACTOR	53
4.6	CALCULATION OF POWER	57
4.7	FUNCTION AND POWER REQUIREMENT OF ZIGBEE MODULE	59
4.8	CONCLUSION	60
CHAPTER 5: CONTROLLING OF THE APPLIANCES		62
5.1	INTRODUCTION	63
5.2	COMPONENTS USED FOR CONTROLLING	63
5.3	PCB FILE SHOWING CONTROL COMPONENTS IN THE DEVELOPED CIRCUIT	68
5.4	DIFFERENT CONTROL ALGORITHMS	68
5.5	ROLE OF ZIGBEE	70
5.6	PURPOSE OF MANUAL SWITCH	70
5.7	CONCLUSION	71
CHAPTER 6: EXPERIMENTAL RESULTS AND ANALYSIS		74
6.1	INTRODUCTION	75
6.2	CONNECTION OF ELECTRICAL SENSING UNIT TO THE APPLIANCES	75
6.3	DATA RECEPTION	76
6.4	CORRECTION FACTOR	80
6.5	ZIGBEE DATA FORMAT	81
6.6	DISPLAYING OF THE DATA	83
6.7	CONCLUSION	85
CHAPTER 7: CONCLUSION AND FUTURE WORKS		88
7.1	RESEARCH OBJECTIVE	89
7.2	RESEARCH OUTCOME	89
7.3	FUTURE WORKS	90

CHAPTER 8 : REFERENCES

93

PUBLICATIONS

103

List of Figures

Figure 1: Key Elements of Smart Grid..... 3

Figure 2: Building blocks of an Electric Power System..... 6

Figure 3: Block diagram of the developed system 7

Figure 4: A Simple model of a Shunt Resistor 20

Figure 5: XBee Chip Series 2..... 30

Figure 6: XCTU Configuration tab..... 31

Figure 7: XBee Explorer and USB Cable 32

Figure 8: Screenshot of XBee Coordinator Configuration 33

Figure 9: Screenshot of XBee End Device Configuration..... 35

Figure 10: XBee-Coordinator Configuration Algorithm 36

Figure 11: XBee Data-Packet Identification..... 37

Figure 12: Extraction of Data Bytes for further processing 38

Figure 13: Functional block diagram of the system 44

Figure 14: Basic block diagram of the circuit 44

Figure 15: Designed smart voltage and current sensing circuitry 46

Figure 16: Sensing Unit connected to room heater and electric bulb 47

Figure 17: Voltage Transformer circuitry 48

Figure 18: Circuit schematic for voltage measurement..... 49

Figure 19: Current waveform of the electric heater 50

Figure 20: Current waveform of the electric kettle..... 51

Figure 21: Current waveform of the toaster 51

Figure 22: Current Transformer Circuitry 52

Figure 23: Circuit schematic for current measurement..... 53

Figure 24: Representation of power factor..... 53

Figure 25: Circuit schematic of developed system 58

Figure 26: Fabricated PCB for smart power monitoring unit..... 59

Figure 27: Pictorial view and Symbol of Triac BT138 64

Figure 28: Pictorial view of S2S3 Phototriac coupler and its Symbol 66

Figure 29: Standard Circuitry of S2S3 with Triac..... 66

Figure 30: PCB File showing S2S3 and BT138 assembly 68

Figure 31: Hardware Unit showing the Manual Switch..... 71

Figure 32: Connected electrical devices to the sensing unit..... 76

Figure 33: X-CTU terminal Displaying Sensor Hex Values 82

Figure 34: XBee Coordinator Data Format 82

Figure 35: Prototype of the Smart power monitoring system and Graphical User Interface 84

<i>Figure 36: Screenshot of Developed GUI.....</i>	<i>85</i>
--	-----------

List of Tables

<i>Table 1: WiFi Generations [83]</i>	<i>27</i>
<i>Table 2: Comparison of Wireless Technologies</i>	<i>29</i>
<i>Table 3: XBee test results for current output signal</i>	<i>79</i>
<i>Table 4: Percentage error of received voltage, current and measured power</i>	<i>81</i>

List of Graphs

<i>Graph 1: Testing the strength of ZigBee radio signal with respect to the changes in the displacement between coordinator and end device</i>	<i>39</i>
<i>Graph 2: Output waveform of the current transformer for a 60 W electric bulb.....</i>	<i>55</i>
<i>Graph 3: Output waveform of the current transformer for a 100 W electric bulb.....</i>	<i>55</i>
<i>Graph 4: Output waveform of the current transformer for a 800 W room heater</i>	<i>56</i>
<i>Graph 5: Output waveform of the current transformer for an audio device.....</i>	<i>56</i>
<i>Graph 6: Gate Trigger Current as a function of Junction Temperature</i>	<i>65</i>
<i>Graph 7: Minimum trigger Current vs. Ambient Temperature.....</i>	<i>67</i>
<i>Graph 8: output waveform of voltage transformer</i>	<i>77</i>
<i>Graph 9: output waveform of current transformer-1 for Low Loads.....</i>	<i>78</i>
<i>Graph 10: output waveform of Current Transformer-2 for High Loads</i>	<i>79</i>