DESIGN AND IMPLEMENTATION OF FPGA BASED SMART ENERGY DISTRIBUTION MANAGEMENT SYSTEM

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***ABSTRACT*:** *This research presents the design and implementation of smart energy management system (SEMS) and control for monitoring of efficient load management for photovoltaic power generation system and utility source. The design comprises of an Energy Management Center (EMC) and Field Programmable Gate Array (FPGA).Energy management center is basically simple and easy to use graphical user interface, developed in LABVIEW to show and monitor the run time data logging of voltages and currents and also to communicate with FPGA. Analog to digital converter is used to interface the current and voltage sensors with FPGA. ZigBee is used for wireless radio data transmission between the FPGA and energy management center.*

Keyword: FPGA, Renewable Energy, Smart Grid, Smart Energy Management, ZigBee

1. INTRODUCTION

Due to increase in electrical energy demand installation of thermal power plants are needed. Steam is work as prime mover source in thermal power plants. First the water is heated and vaporized and then it spins a turbine which drives an electrical generator. But this arrangement also increases the cost of electrical energy. It is also not an eco-friendly arrangement because it emits CO_2 and polluted the atmosphere. The cost effective solution for the generation of electrical energy is the use of integrated power of utility source and renewable energy resource and also eco-friendly. Smart energy management system for this integrated arrangement avoids the blackout which is caused by the conventional load shedding. [1, 2, 4, 6]

The social economic development energy resources are the backbone of any country to contribute revenue in the budget. For the lightning of cities, running the industries and transportation energy is necessary. The rapid increase in power demand poses a serious challenge for power distribution systems because of industrial advancement, population increase and living standards advancement.

Energy crisis is increasing in Pakistan due to insufficient production of energy. To meet the increasing energy demand, Pakistan is facing the critical energy problems and because of transmission failures the situation is also even worse due to shortage of hydropower, stealing of electricity and obsolete facilities. Distribution companies follow the load-shedding trends/methods to avoid the system failure or major breakdown where total generation is smaller than energy demands. Further, tripping of feeders originating from a substation is also observed a common practice.

To accomplish shortage of energy, different renewable energy resources are used. Renewable energy resources contribute a significant role in the energy management solutions. In energy management they are difficult to interconnect with main electric utility. They need to be managed with electric utility [1]. Energy management is a subject of great significance. It consists in selecting between a set of sources that are able to produce energy for loads by reducing costs and losses in distribution area. [2]

Timely power demands; solar cell generation depends on current storage battery status and weather conditions are the variables that we need to take into account for the improvement of efficiency of energy management system. In the currently available solutions these variables are not considered, so to achieve high efficiency from SEMS is quite difficult. Thus, for higher efficiency of a SEMS these variables need to be acquired/monitor.

In this paper we present the design and implementation of SEMS of utility source and photovoltaic power system based on FPGA. The smart energy management system is implemented on Spartan 3AN FPGA using Xilinx ISE tool and in LABVIEW and verifies the performance as to how competently it manages energy using photovoltaic power system and utility source. Different techniques are implemented for this purpose. As the technology developed, smart energy management system has emerged as an effective tool for saving energy. This is important to increase the efficiency of smart energy management system and to reduce the energy cost.

Verilog HDL coding and synthesis will be done in Xilinx ISE Tools. Model of FPGA will be finalized after completion of synthesis. The number of combinational logic blocks (CLBs) and lookup tables (LUTs) used to implement the design.

The key objective of the research is to design and implement smart energy management system for increasing the efficiency of a system.

- To design and implement efficient algorithm on FPGA.
- To provide proper power management services and improves efficiency.
- Architecture design of SEMS and hardware Implementation

2. RELATED WORK

Renewable energy systems such as wind power generation, fuel cells and photovoltaic power generation are getting a huge attention globally. As compare to other generating systems such as thermal and nuclear power plants, Renewable energy systems are eco-friendly because they are not emitting pollution like emission of a large amount of CO_2 to the atmosphere when they generate electrical energy from thermal power plant and also do not discharge nuclear wastes as in nuclear power plants[9].

Renewable energy systems have a host of economic benefits, social benefits and environmental benefits. To solve several energy problems, renewable energy systems are considered as the important solution. They have also some disadvantages like steady output power can be obtained from thermal and nuclear plants but the renewable power generating plants such as wind mills and solar power generation do not provide steady power because it depends on the weather conditions, hourly variation and season[1].

At noon, maximum power can be achieved from photovoltaic power system and minimum power can be achieved from wind mills whereas, at night time no power can be achieved from photovoltaic power system and maximum power achieved from wind mills [1, 7] Due to non-steady power they also require energy storage system but because of higher costs they are not easy to install on large scale. [8]

In this paper, we have proposed SEMS which have emerged as an effective tool for saving energy. This is important to increase the efficiency of system and to minimize the cost.

Renewable energy has some disadvantages. The Output power of thermal power plants and nuclear power plants is stable, but output of renewable power plants like photovoltaic power system and wind power generation systems is not give stable, depending on season and weather condition and also on hourly variation. In general, at noon photovoltaic power generation system gives maximum power but on night time it never gives an output, whereas wind power generation system gives minimum power at noon in comparison of morning or at night timings. [10]

Ability of photovoltaic power generation system is to generate electrical energy in a noiseless, clean and reliable way. They never release any greenhouse gases into atmosphere because they simply absorb light energy rather than burning of a fuel in order to generate the electrical output. There is nothing any type of moving part in PV system, so PV system is silent and practically maintenance-free. We are also able to track the PV system from inside of home.

Fig.1 shows the use and connectivity of photovoltaic power system source and utility source. PV panels convert the sun's energy into direct current (DC) electricity. Electrical generated power depends on the number of PV panels used. Inverter converts the electricity from DC to AC [10, 15].

In [1] Intelligent energy management system (IEMS) for photovoltaic power generation system and utility source is presented. IEMS is a part of a smart grid that can enable demand response applications for domestic customers. IEMS algorithm is developed for managing higher electrical load appliances. Domestic loads are managed by algorithm according to their precise priorities and guarantee the total consumption of electrical load appliances below definite levels. [2] Energy Management is a method to decrease the power consumption of electronic system by selectively shut off the priority system. [4]

There are several studies and different commercial products including wind power and photovoltaic power in propagation of environment friendly technologies and they have significant roles. The power market would become more significant and the sustainable development of renewable energy as the influence of the smart grid is expected at wider scale. It is possible that the impact of renewable energy, sustainable growth will be much larger with the Smart Grid. In this type of generating systems, the interconnectivity of electric utility with renewable energy resources is difficult. Renewable energy resources need to be managed with electric utility. Moreover, renewable energy sources provide power which is more or less indefinitely, but this problem is expected to be stable. Therefore, for greater performance of renewable energy sources and to monitor these criteria, an intelligent system is needed. Also provides proper management services. [5]

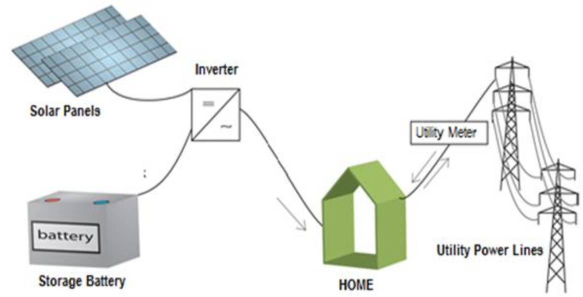


Fig.1. Photovoltaic Power System source and Utility Source [3]

In [6] SEMS is presented for effective electrical load management. It has two parts first is energy management center (EMC) containing graphical user interface (GUI). The runtime information is shown by EMC; it also keeps the data logging with electrical load control. Other part is load scheduling. For the illustration of results of load scheduling MATLAB simulations are used. Implemented hardware model is using human machine interface (HMI) and contains PIC18F4520 microcontroller and Zigbee.

3. SYSTEM ARCHITECTURE AND IMPLEMENTATION

Hardware Architecture of SEMS is shown in Fig.2. It contains of the load transfer switches, analog to digital converter, ZigBee, Hall Effect current sensors, voltage sensors and control unit. The control unit part is situated in the middle. The SEMS offers the ability to sense the consumed power, transfer load to photovoltaic power system and utility source according to the usage and sends information through the ZigBee to EMC.

3.1 Field Programmable Gate Arrays

The desired SEMS will be implemented using Xilinx ISE Tools and Spartan 3AN Field Programmable Gate Arrays (FPGA) starter kit will be used as the hardware platforms. Verilog HDL coding and synthesis will be done in Xilinx ISE Tools. Model of FPGA will be finalized once the synthesis is complete and the number of combinational logic blocks and lookup tables used to implement the design. Microcontroller processing speed is less than FPGA because FPGAs are concurrent while microcontroller is always sequential. This makes FPGAs better suited for real-time applications. FPGA are flexible, we can add /subtract the functionality as required. Another advantage of using FPGA is to reduce the size of hardware.

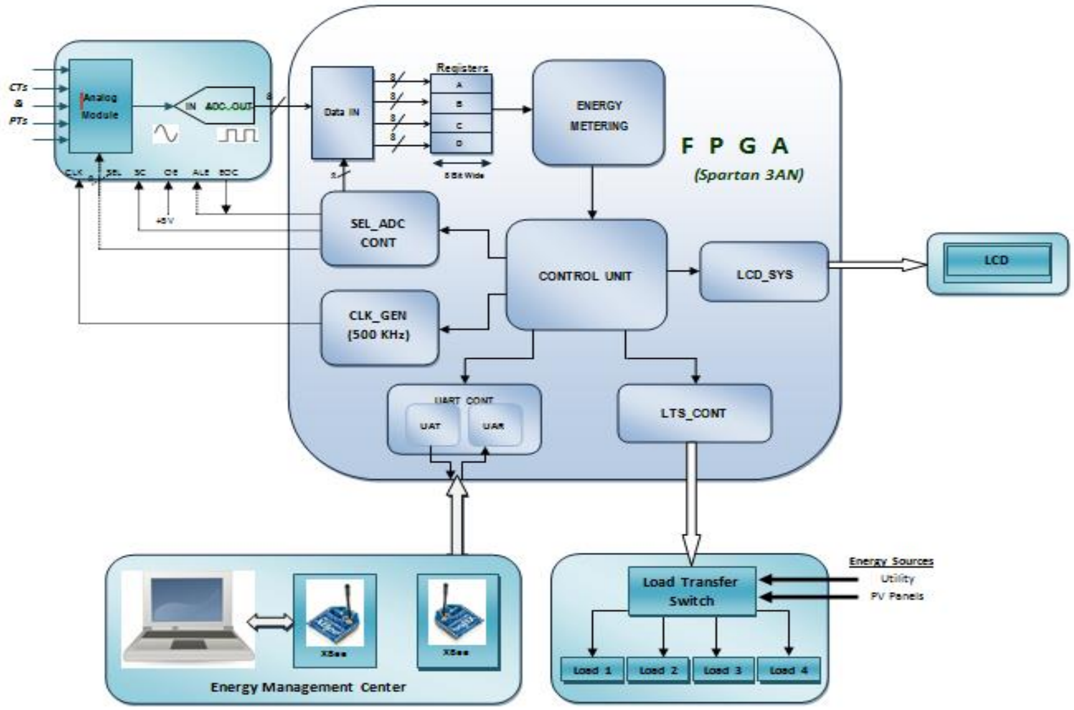


Fig.2. Hardware Architecture of Smart Energy Management System

FPGA are the programmable semiconductor IC. FPGA based around a matrix of Configurable Logic Blocks (CLBs) connected through programmable interconnects. I also consist of Logic Cells (LCs), Look up Tables (LUTs) and input Output Blocks (IOBs). [14] FPGAs allow the designers to modify their designs even after finalizing the manufactured product and installed in the field. They also allow for field advancements to be completed remotely, eliminating the costs associated with re-designing or physically upgrading the system.

Microcontroller processing speed is less than FPGA because FPGAs are concurrent while microcontroller is always sequential. This makes FPGAs better suited for real-time applications. Another advantage of using FPGA is to reduce the size of hardware. [11]

The smart energy management system design is implemented on Spartan 3AN FPGA Starter kit, which is used as control unit and works as brain of an SEMS. The synthesis diagram of SEMS controller is shown in Figure 3 the blue blocks are presenting the Flip-flops and number of mux's used to forward the proper values between stages. The red lines are presenting the buses and the control signals. The Device Utilization and Timings summaries are shown in Table 1 and Table 2

Table 1: Device Utilization Summary

Logic Utilization	Used	Available	Utilization
Number of Slices	1734	5888	29%
Number of Slice Flip Flops	373	11776	3%
Number of 4 input LUTs	3334	11776	28%
• Number used as logic	3318		
• Number used as RAMs	16		
Number of bonded IOBs	20	372	5%
Number of GCLKS	2	24	8%

Table 2: Timing Summary

Parameters	Values
Maximum Frequency	41.389MHz
Minimum period	24.161ns
Minimum input arrival time before clock	4.242ns
Maximum output required time after clock	7.453ns
Maximum combinational path delay:	No path found

Xilinx Spartan 3AN FPGA Starter kit is used as control unit, which is the brain of an SEMS. ADC 0809 provides input of physical quantities to control unit, which is taken from sensing part i.e. current transformers and potential transformers. FPGA receives information from ADC and stored it in temporary registers. For the working of ADC, five 1-bit control signals are also generated from the FPGA. These controls signals are Start Conversion (SC), Output Enable (OE), Address Latch Enable (ALE), End of Conversion (EOC), Clock of 500 KHz (CLK) and Select (SEL) as declared in Fig. 2.

The stored information is processed by the Energy Metering block i.e. voltages, currents and powers of utility and PV system.

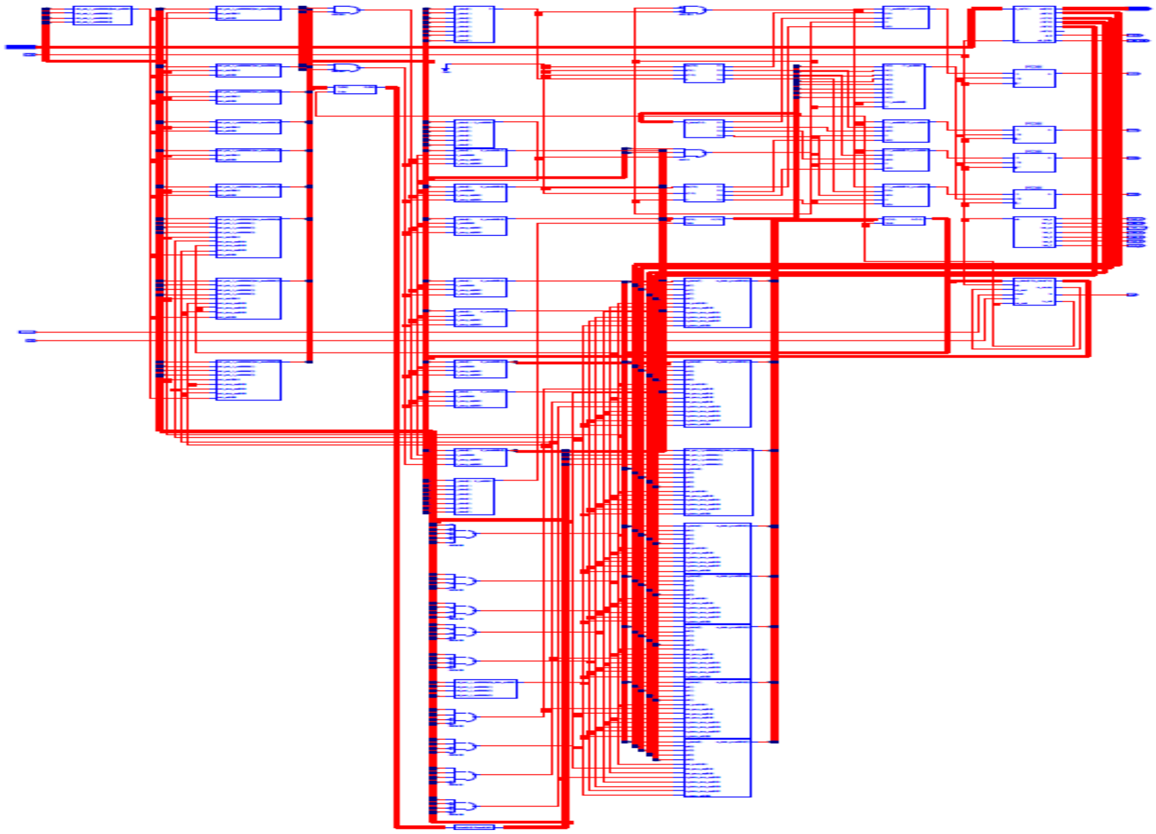


Fig.3. Synthesized Schematic of SEMS

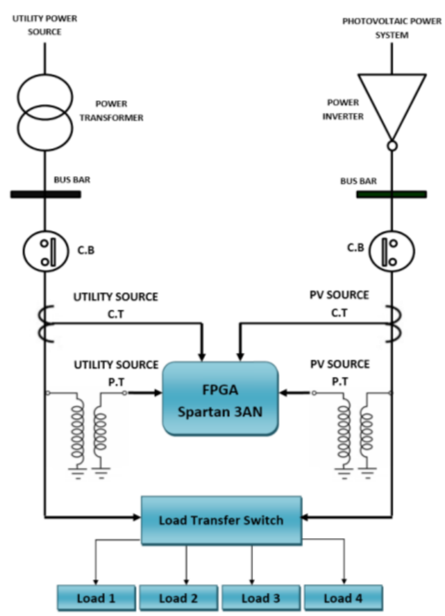


Fig.4. Single Line Diagram of SEMS

The data is then sent to the control unit. Main function of control unit is to control and generate all the control signals and 500 KHz clock for the running of analog to digital converter. FPGA controls the load transfer switch and also sends the data to Energy Management Center (EMC) through universal asynchronous transmitter (UAT) block and Zigbee interface.

FPGA also receives data from Energy Management Center through universal asynchronous receiver (UAR) block and Zigbee interface. Hardware specification of photovoltaic power system is stated in Table *3.*

Table 3: Hardware Specification of Photovoltaic Power System

Classification	Value
Photovoltaic Panel (Pmax)	135W/Panel (Total 810W)
Inverter Rating (Pmax)	4500W
Battery Backup Storage Capacity	220Ah/Battery(Total 1320Ah)
Battery Voltage (Vout)	12V
Battery Power	15840Wh

3.2 Efficiency Based Technique

This technique is based on storage battery and utility power source status. The basic idea of the system based on efficiency is the efficiently working of the SEMS and emphases on the use of the photovoltaic system and utility sources. SEMS collects the information about the utility and the condition of battery status of photovoltaic power system and by the current transformer and potential transformer. The information is then refers to the EMC of SEMS via Zigbee. Where the power consumption is checked and compared it with the power generated by energy sources.

The collected data by the sensors ACS712 and P.T connected at photovoltaic power system and utility sides are transformed into specific factor (f).The SEMS decides whether it uses the power from photovoltaic power system or from utility source.

Factor (f) is basically the difference of the available battery power of photovoltaic power system in watts and the expected power demand i.e. current power consumption in watts. Default value of available source = 0.33

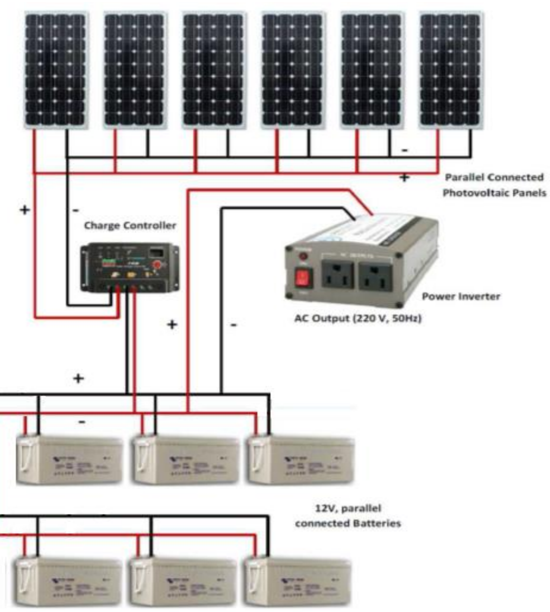
$$f = \frac{Available\ power\ of\ PV\ power\ system\ -\ Load\ consumed}{Load\ Consumed} \quad (1)$$

The system chooses to use the photovoltaic power system or utility source on the bases of following conditions.

f > Default Value: use power from the photovoltaic power system

f = Default Value: use power from both sources (utility source and photovoltaic power system)

f < Default Value: use only power from the utility source

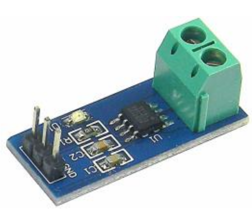


(a)

(b)

(c)

(d)



(e)

Fig.5. (a) Photovoltaic Power Generation System (b) 6 Photovoltaic panels (c) Electrical Contactor Relays for Load Transfer (d)Spartan 3AN FPGA starter kit (e) ACS 712 Hall effect Current sensor

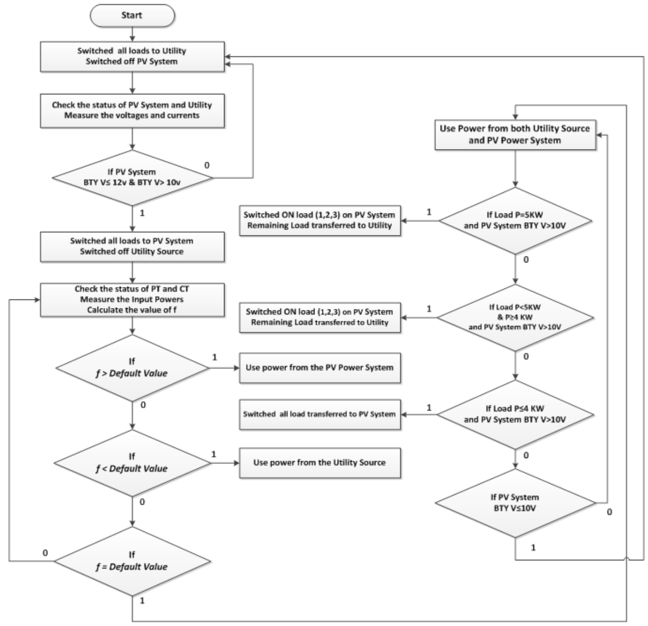


Fig.6. Algorithm of Efficiency Based Technique.

If f is higher than default value, SEMS selects to use power from photovoltaic power system. If f equals to the default value, SEMS selects to use power from both sources i.e. utility source and photovoltaic power system and turn off the photovoltaic power system power. When f is smaller, SEMS chooses to use the utility source. According to the batteries efficiency, default value is adjusted. Algorithm of efficiency based technique is shown in Fig. 6.

3.3 User Based Technique

This is a load priority method. User based technique is a simple method of the selection of energy source according to the requirement of electrical load. For user based technique EMC has a switch to select the working mode. Four switches are also available for managing load priorities. The SEMS controls the power except for loads which have priority. The user based technique manages the complete system for the ease of consumer's. It has a simpler algorithm as shown in Fig 7.

3.4 Normal Load Control Technique

Normal load control technique is based on run time load control method. The load can be controlled from energy management center from where user can easily switched ON/OFF the load according to the load requirement. Energy management system is basically a LABVIEW based graphical user interface. By switching ON/OFF EMC sends information to the FPGA via zigbee interface for transferring the load on utility power source or on photovoltaic power system

3.5 Energy Management Center

Energy Management Center (EMC) is basically simple and easy to use graphical user interface for monitoring and data logging of voltage and current of photovoltaic system and utility. It has voltmeter, ammeter and power meter for the indication and measurement of utility and also for photovoltaic power system. Voltage, current and power data's are shown on these meters. Data are updated on every second for data logging

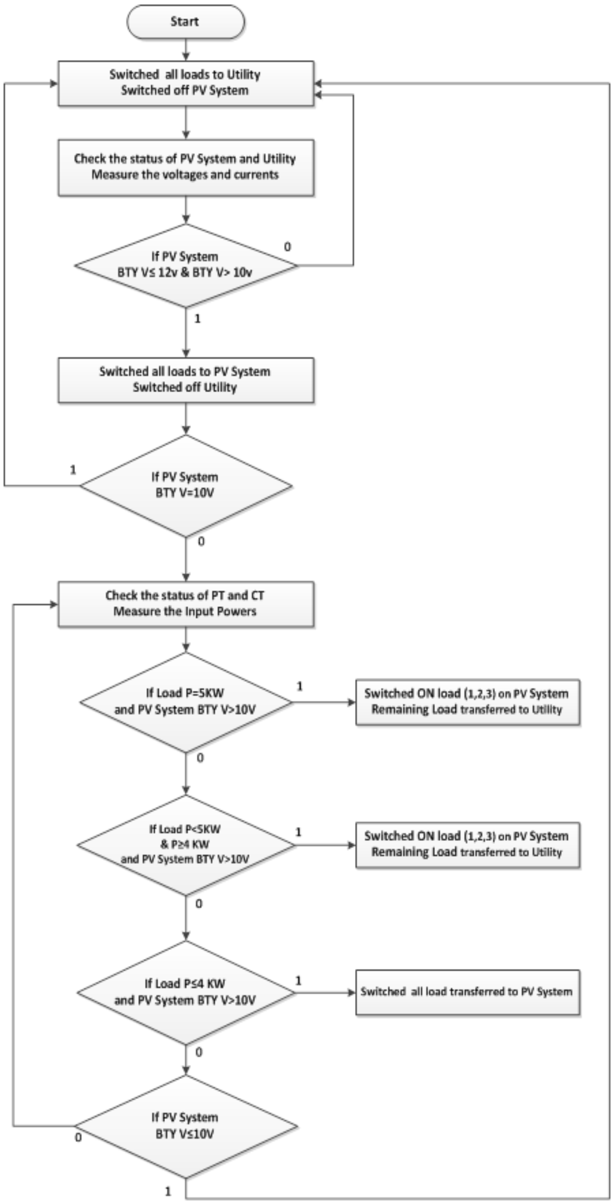


Fig.7. Algorithm of User Based Technique.

of voltage and currents in a table. It has three switches i.e. EOT, UOT and NLC used for the selection of efficiency based technique, user based technique and for normal load control scheme respectively. For normal load control scheme other four switches are also available for the transfer of loads between photovoltaic power system and utility source. The snap shots of EMC interface are shown in Fig 8 and Fig 9.

4. EXPERIMENTAL RESULT

Proposed system is implemented on Spartan 3AN FPGA starter kit and Lab VIEW. Verilog HDL programming is used in Xilinx ISE to implement Smart Energy Management Systems controller on FPGA. For hardware implementation FPGA, two ACS 712 Hall Effect current sensors and two potential transformers are installed to gather information of photovoltaic power system and utility source. ZigBee pair is used to transfer the essential information between LABVIEW and Spartan 3AN FPGA Starter kit. Photovoltaic power system is installed with the help of six solar panels, a charge controller, four batteries and an inverter. Energy Management Center is used as graphical user interface for the monitoring and data logging of voltages and currents of photovoltaic power system and utility source. It is developed in LABVIEW to communicate with FPGA.

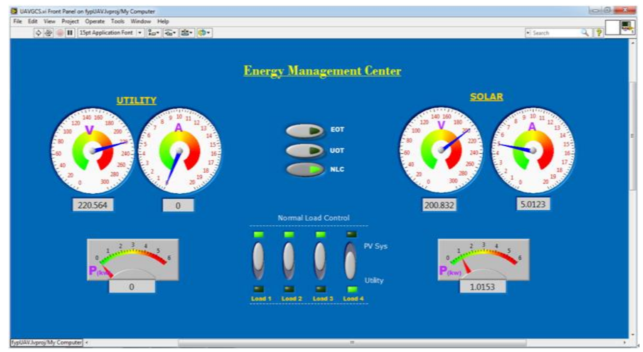
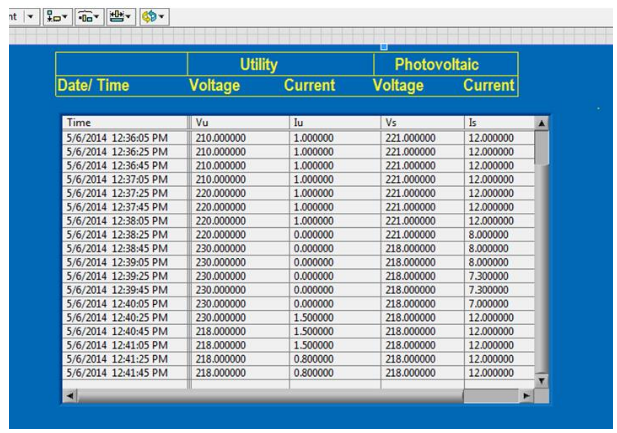


Fig.8. Main window of EMC



	Utility		Photovoltaic	
Date/ Time	Voltage	Current	Voltage	Current
Time	Vu	Iu	Vs	Is
5/6/2014 12:36:05 PM	210.000000	1.000000	221.000000	12.000000
5/6/2014 12:36:25 PM	210.000000	1.000000	221.000000	12.000000
5/6/2014 12:36:45 PM	210.000000	1.000000	221.000000	12.000000
5/6/2014 12:37:05 PM	210.000000	1.000000	221.000000	12.000000
5/6/2014 12:37:25 PM	220.000000	1.000000	221.000000	12.000000
5/6/2014 12:37:45 PM	220.000000	1.000000	221.000000	12.000000
5/6/2014 12:38:05 PM	220.000000	1.000000	221.000000	12.000000
5/6/2014 12:38:25 PM	220.000000	0.000000	221.000000	8.000000
5/6/2014 12:38:45 PM	230.000000	0.000000	218.000000	8.000000
5/6/2014 12:39:05 PM	230.000000	0.000000	218.000000	8.000000
5/6/2014 12:39:25 PM	230.000000	0.000000	218.000000	7.300000
5/6/2014 12:39:45 PM	230.000000	0.000000	218.000000	7.300000
5/6/2014 12:40:05 PM	230.000000	0.000000	218.000000	7.000000
5/6/2014 12:40:25 PM	230.000000	1.500000	218.000000	12.000000
5/6/2014 12:40:45 PM	218.000000	1.500000	218.000000	12.000000
5/6/2014 12:41:05 PM	218.000000	1.500000	218.000000	12.000000
5/6/2014 12:41:25 PM	218.000000	0.800000	218.000000	12.000000
5/6/2014 12:41:45 PM	218.000000	0.800000	218.000000	12.000000

Fig.9. Data Logging Window of EMC

Three energy management techniques are tested: efficiency based technique, user based technique and normal load control technique. Experimentations for these techniques are performed over three sunny days and five different electrical loads are used. In user based technique and normal load control technique loads are given priorities for the switching of load transferring to photovoltaic power system and utility source. The results of the three techniques are shown in fig10, 11 and 12.

Figure 10 shows the hourly variations of power consumption with respect to time in normal load control technique in Figure11 shown the power consumptions decrease from 7:00 to 13:00 in both users based and efficiency based techniques. In comparison with normal load control, efficiency based and user based techniques have improvement of 14.42 percent and 11.62 percent respectively in overall power consumption as shown in figure 12. Above the dotted line in figure 13 utility sources is used by the load whereas below the line power of photovoltaic power system is used. Efficiency can be further improved by extending battery backup and increase in number of photovoltaic panel installation.

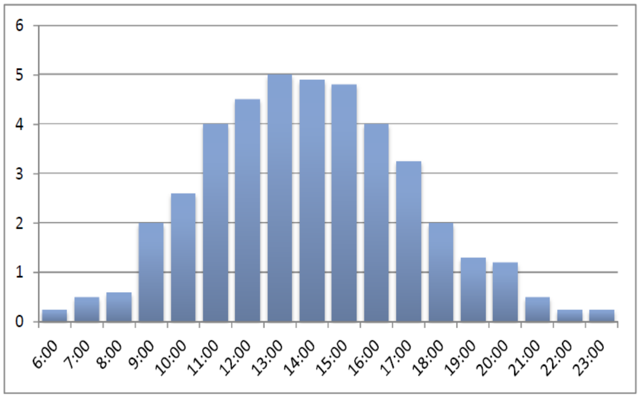


Fig.10. Hourly variations of power consumption w.r.t time in normal load control technique

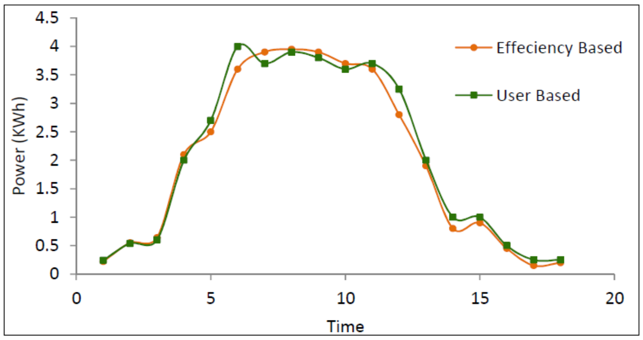


Fig.11. Power consumption w.r.t time in SEMS in user and efficiency based techniques

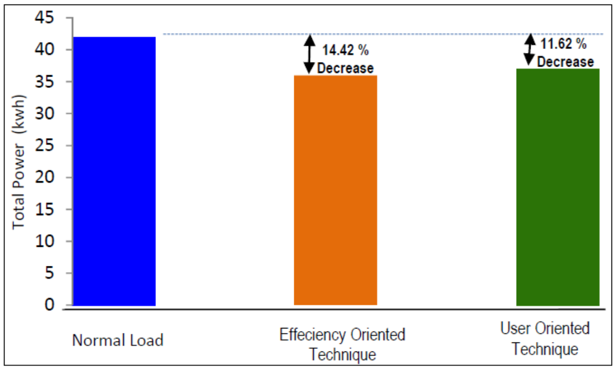


Fig.12. Experimental Result of Implemented SEMS

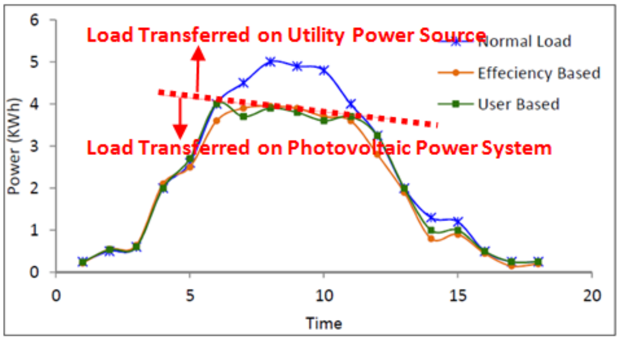


Fig.13. Power consumption comparison of Implemented SEMS

5. CONCLUSION

The SEMS is designed for managing/improvement of energy efficiency of photovoltaic power system and utility source. The system is designed on Xilinx ISE using Spartan 3AN FPGA and LAB VIEW. The proposed system is cost effective which improves energy efficiency and gives an incentive to user. Users can easily monitor and manage their electricity loads according to the requirements by using Energy Management Center. Information of the daily consumed electricity is also stored in a file. User can also view their daily consumptions. If the number of photovoltaic panels and storage backup are improved, SEMS also improves the energy efficiency.

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