Design and Implementation of Fuzzy Logic Controlled Uninterruptible Power Supply Integrating Renewable Solar Energy

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*Abstract—**The control and operation of electronic systems relies and depends on the availability of the power supply. Rechargeable batteries have been more pervasively used as the energy storage and power source for various electrical and electronic systems and devices, such as communication systems, electronic devices, renewable power systems, electric vehicles, etc. However, the rechargeable batteries are subjected to the availability of the external power source when it is drained out. Because of the concern of battery life, environmental pollution and a possible energy crisis, the renewable solar energy has received an increasing attention in recent years. A fuzzy logic control based grid tied uninterruptible power supply integrating renewable solar energy can be used for electrical and electronic systems to produce power generation. This paper presents the design and implementation of fuzzy logic control based grid tied uninterruptible power supply integrating the renewable solar power energy system. The uninterruptible power supply (UPS) system is characterized by the rechargeable battery that is connected with the Photovoltaic Panel through the DC/DC converter, the utility AC through the AC/DC converter and the load is connected through the DC/AC converter. The whole operation is controlled by the fuzzy logic algorithm. A complete hardware prototype system model of the fuzzy logic control based on the grid tied uninterruptible power supply integrating with the renewable solar energy is designed and implemented. The operation and effectiveness of the proposed system is then demonstrated by the actual and real time implementation of the fuzzy logic control grid tied operation uninterruptible power supply integrating renewable solar energy connected to the rechargeable battery bank and a PIC microcontroller platform for fuzzy logic control and operation***

Keywords—Fuzzy Logic Control, Solar Energy, Utility AC, Uninterruptible Power Supply

I. Introduction

Nearly all electrical power comes from fossil fuels (e.g., coal and oil) and once that these fossil fuels have been burnt; they are gone forever. Burning the fossil fuels creates pollution; this in its turn is having a growing and adverse effect on the regulation of the earth's climate. The more energy people use each day, then the less there is left for the future. There is a worldwide need to reduce the amount of energy consumption, and everybody has his part to play whether in industry, transport, business, construction, or at home. Consuming less energy and being more efficient in the way people run their homes will naturally save money and protect the environment as well. At the same time, it will help protect the environment and safeguard the future. The energy production has become expensive worldwide and its shortage has lead to intensified research studies for developing alternate sources of energy which are clean, pollution free, and eco friendly. Due to the increasing global interest on the conservation of environment, renewable energy systems are gaining attention in the recent years [1]. According to [2], advanced solutions must be applied to design and control clean power generation, energy harvesting, and energy storage systems which must then guarantee efficiency, robustness, safety, reliability, and sustainability. Hence, using the electricity wisely is good for the environment which saves money in homes, businesses, and nation's energy supply. One of the many ways of saving and controlling the use of electricity is to have a power supply. Known electronics equipment nowadays including household appliances used power supply in order to operate them. Without the power supply, it is impossible for us to run those appliances. A power supply is a device that supplies electrical energy to one or more electric loads. It may also refer to a device that converts one or another form of energy (e.g., mechanical, chemical, solar) into electrical energy. It is most commonly applied to devices that convert one form of electrical energy into another. In all aspects, every power supply needs an external power for it to run, and every power consumed by its load or electronic circuitry directly attached to it is proportional to the household power consumption, and power consumption is proportional to the bill of payments. Knowing the importance of power supply and its proper application can truly help conserved energy. Problem associated with the utility alternating current (AC) source is brown outs. The power interruption is a problem associated with the AC power supplied by the utility company. In many cases, electricity is needed in emergency situations. The integration of renewable energy source such as solar energy can help provide uninterruptible power supply. The general objective of this paper is to design and implement a fuzzy logic based uninterruptible power supply integrating sustainable solar energy source with the power supplied by the utility company. The specific objectives of this paper are the following: (a) to design a fuzzy logic controller (FLC) for the uninterruptible power supply integrating solar energy with a power from the utility company, (b) to build and construct a prototype incorporating the solar energy source, utility AC source, and fuzzy logic controller for uninterruptible power supply, (c) to design the AC/DC converter for the utility AC source, the DC/DC converter for solar energy source, and the DC/AC converter for the load and, (d) to test the performance of the system. As it was stated in [4], energy is of great concern and without it, almost all electrical and electronic devices will become immobilized and useless. Power electronics and renewable energy systems has been established as a major discipline in electrical and electronics engineering which is now an indispensable tool for the modern industrial automation, high efficiency energy system, and energy conversion that plays a

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dominant role in solving the global warming problem, which appears to be a very serious concern in our modern society [5]. Its applications are fast expanding in industrial, commercial, transportation, utility, aerospace, and the military environments primarily due to the reduction of cost, size, and improvement of performance. The widespread usage of the renewable energy systems is inevitable in the global industrial automation, energy conservation, and environmental pollution control. It appears that the role of power electronics and renewable energy systems on our society tends to be as important and versatile as that of the information technology today because of environmental concern [5]. This paper includes the design and implementation of a fuzzy logic controller for the uninterruptible power supply integrating the solar energy whose components are limited to supply alternating current (AC) to the target load. This paper employs also a prototype for the purpose of demonstrating the concept of renewable solar energy source for power saving equipment that can be operated all the time. The prototype model is limited to a photovoltaic system driving the DC/DC converter and storing its charge to the battery bank. If in case the solar energy is not available, the utility AC source shall trigger and drives the AC/DC converter charging the battery bank. The battery bank used in the study is the Motolite Solar Master Deep Cycle and it is connected to the DC/AC converter which in turn supplies the load. The fuzzy logic controller is responsible for control and monitoring the entire system. Data logging and monitoring is also included to measure the voltages and currents obtained during system test.

II. Methodology

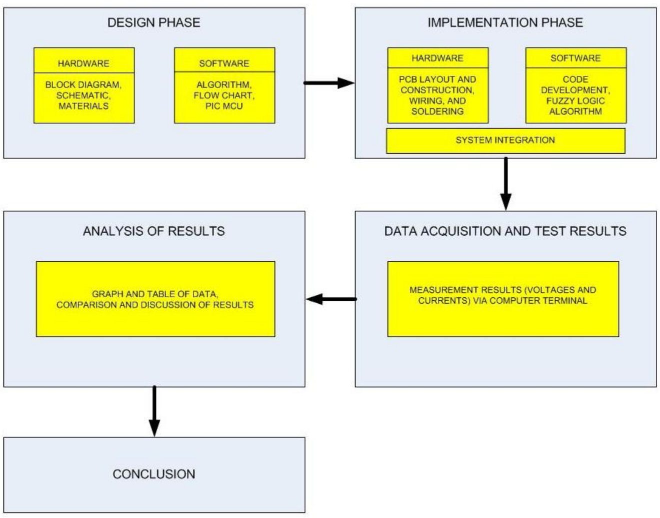

Fig. 1. Methodology of the study.

The block diagram as it was shown in figure 1 illustrates the methodology and procedural steps used in conducting this research study. The design phase refers to the actual planning for the hardware and software of the system. It includes the determination of the conceptual framework and materials used for the hardware design and implementation. It also refers to the determination of the algorithm, program flow chart, and type of microcontroller used for the software implementation. The implementation phase refers to the construction of the circuits based on the block diagram and schematic obtained from the design phase. In this phase, software coding was done for the fuzzy logic algorithm. The software and hardware are integrated in this phase for testing. The system test phase refers to the experimental testing of the system prototype. The performance of the hardware and software is tested. The communication between the controller and different modules associated with the solar, utility AC, converters, battery, and the load are also tested. Data logging, readings, and measurements are collected through the LCD display and computer hyper terminal via RS232C for analysis. Several samples are gathered in order to verify the validity of the data. The analysis of results phase refers to the processing of data to yield a conclusion that is based on the set objectives. The graphs and comparison of data are shown in the measurement results section. A conclusion is given thereafter.

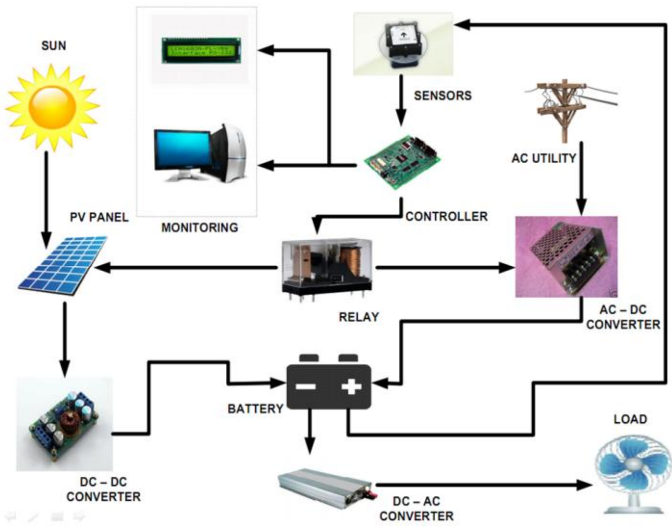

Fig. 2. Conceptual framework of the system.

Figure 2 shows the conceptual framework of the system. The design of the system involves the integration of the hardware and software. The system are also consists of two input source supply which are solar energy and utility alternating current (AC). The solar source is connected to the DC/DC converter such that a smooth continuous DC power will supply the battery bank. By default, the Solar Energy source is the priority source of supply. For the AC utility source, the AC/DC converter is connected. The system continuously monitors the solar voltage, DC/DC voltage, battery voltage, charging current, load current, and AC inverter voltage. The battery bank is connected to the DC/AC converter to supply the load. The PIC16F877A MCU controller governs the entire system. A relay driver circuit is used for switching of source supply. The system consists of two displays for data logging and monitoring, the LCD 16x2 character display and the RS 232C serial interfaced with computer hyper terminal. PV system consists of solar panels, DC/DC voltage converters, controllers, and batteries. DC/DC voltage converters are used for matching the characteristics of the load with those of the solar panels. The use of the battery allows the photovoltaic system to behave as a real source to the feeder so that it may exhibit constant voltage levels corresponding to the different loads. The battery is also required for saving power as well as temporary compensation for power variations. DC/DC voltage converters

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are classified into three categories, namely boost converters, buck converters, and buck/boost converters. The selection of the type of DC/DC voltage converter depends on the voltage levels involved. In this case, the authors have used the buck boost DC/DC converter.

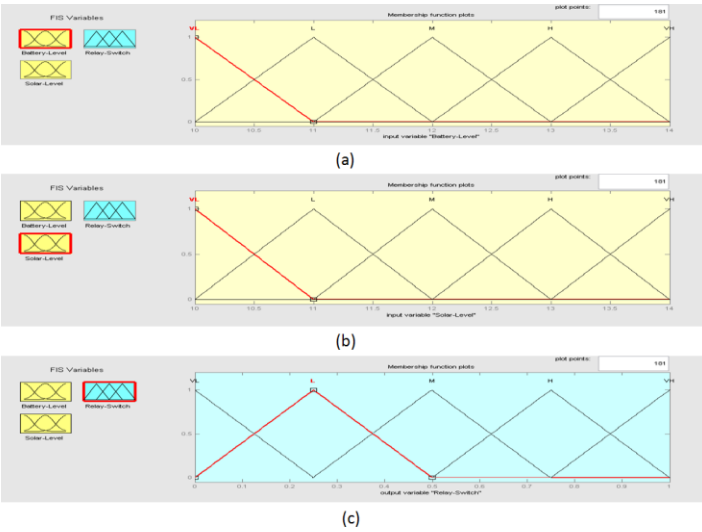

Fig. 3. Graphical representation of membership functions for input linguistic variables: (a) battery level, (b) solar level, (c) relay switch.

The fuzzy logic was chosen as the control algorithm. The input is the battery voltage level and the solar voltage level. The output is the switching of relay whether the battery shall be charged by the solar panel through the DC/DC converter or with the utility AC through AC/DC converter. Figure 3 shows the input and output relationship of the fuzzy logic algorithm. The fuzzification is the process of changing a real scalar value into a fuzzy value. The fuzzy variables are used to translate real values into fuzzy values. The possible values of a fuzzy variable are not numbers but the so called linguistic terms. The input linguistic variables for fuzzy logic controller express linguistically with the measured battery voltage level and with the measured solar voltage level from the sensors. A triangular and trapezoidal membership functions are used to fuzzify the input. For the fuzzifier program, it is necessary to determine the range of fuzzy variables related to the crisp inputs. The next step was to define the membership function that will convert raw data values into linguistic terms. The triangular shape functions represented by the input and output membership functions is shown in the figure 4.a. Instead of mathematical formulas, the control algorithm used fuzzy logic rules to make decisions and control action in the form of the IF-THEN statements. Summarizing the output from all the fuzzy rules, a surface plot of solar level, battery level, and relay switch is created as illustrated in figure 4.b.

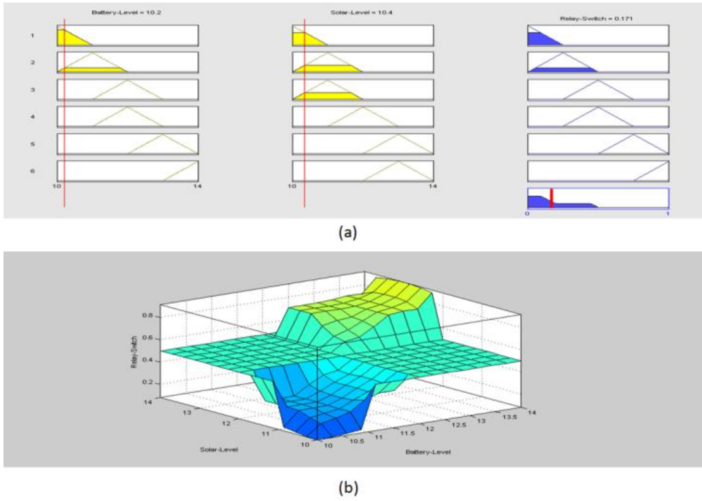

Fig. 4. (a) Fuzzification and defuzzification process, (b) control system plot.

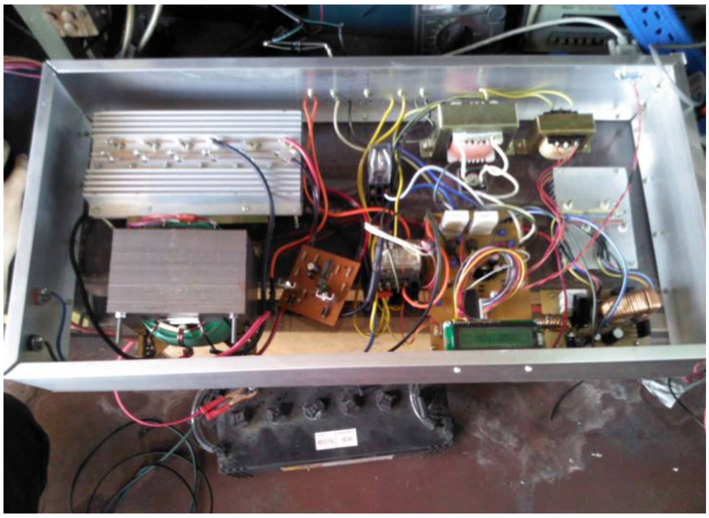

Fig. 5. Design prototype.

Fig. 6. Photovoltaic module installed on roof top during system test.

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Table 1: Data and measurement results during system test.

Date	Time	Solar Voltage	DC/DC Voltage	Battery Voltage	Charge Current	Load Current	AC Inv. Vout
11/1/2013	8:20AM	19.5 V	14.3 V	11.2 V	2.4 A	2.2 A	157 V
11/1/2013	3:20PM	18.9 V	14.2 V	11.1 V	2.3 A	2.1 A	158 V
11/2/2013	9:30AM	18.7 V	14.1 V	11.3 V	2.2 A	2.2 A	159 V
11/2/2013	4:30PM	18.2 V	14.1 V	11.1 V	2.1 A	2.0 A	157 V
11/3/2013	7:30AM	18.3 V	14.1 V	11.2 V	2.1 A	2.0 A	160 V
11/3/2013	3:54PM	18.6 V	14.2 V	11.2 V	2.2 A	2.1 A	159 V
11/4/2013	8:30AM	19.2 V	14.2 V	11.9 V	2.2 A	2.1 A	160 V
11/4/2013	3:30PM	19.1 V	14.2 V	11.9 V	2.4 A	2.0 A	158 V
11/5/2013	7:20AM	19.0 V	14.1 V	12.1 V	2.2 A	2.2 A	160 V
11/5/2013	1:25PM	18.9 V	14.2 V	12.8 V	2.2 A	2.1 A	159 V
11/5/2013	4:00PM	18.9 V	14.1 V	13.3 V	2.2 A	2.1 A	159 V
11/6/2013	10:00AM	18.7 V	14.2 V	12.0 V	2.1 A	2.0 A	158 V
11/6/2013	3:27PM	18.4 V	14.2 V	11.9 V	2.1 A	2.0 A	158 V
	Average	18.8 V	14.2 V	11.8 V	2.2 A	2.1 A	158.6 V

Figure 5 and figure 6 above depicts the overall illustration of the design prototype. It is composed of the battery which is a Solar Master Deep Cycle connected to the DC/AC converter. It constantly supplies the load while it is being continuously charged by the solar photovoltaic system through the DC/DC converter. The DC/DC converter is then configured through the cascade connection of the two basic DC/DC converters which is the buck/boost system where the output voltage could be higher or lower than the input voltage that is coming from the solar photovoltaic system. The AC/DC converter is also connected to the Solar Master Deep Cycle battery through the relay circuit driver.

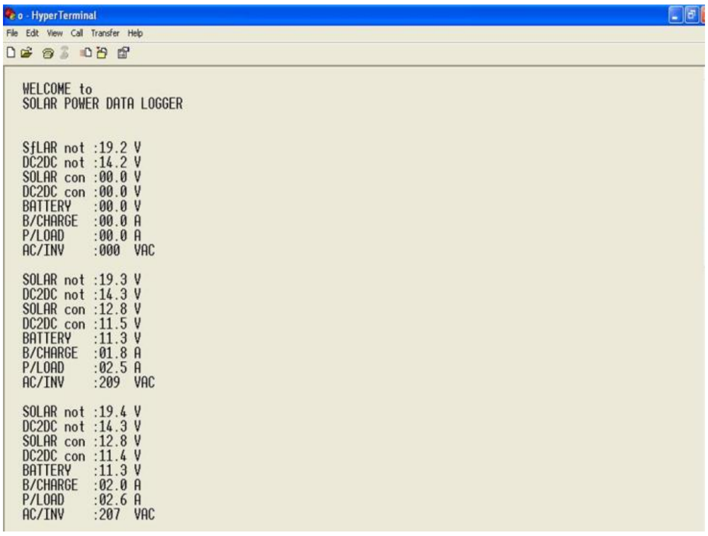

Fig. 7. Data logging through hyper terminal via RS 232C (screen shot).

The hyper terminal program is a terminal emulation software that is capable of connecting to the prototype through the serial COM port (RS 232C). The RS 232C serial port data logger allows real time monitoring and displaying values of solar voltage, DC/DC voltage, battery voltage, charging current, load current, and AC inverter voltage. Figure 7 shows a sample screen shot for the data acquisition using hyper terminal program through RS 232C. The settings of the hyper terminal are as follows: [a] bits per second (9600), [b] data bits (0), [c] parity (none), [d] flow control (none). The test was conducted with several trials at different date and time and also at different conditions of the environment. The data acquisition and readings were obtained both from the LCD display and computer terminal via hyper terminal. The solar voltage, DC/DC voltage, battery voltage, charge current, load current, and AC inverter output voltage were obtained.

III. Measurement Results

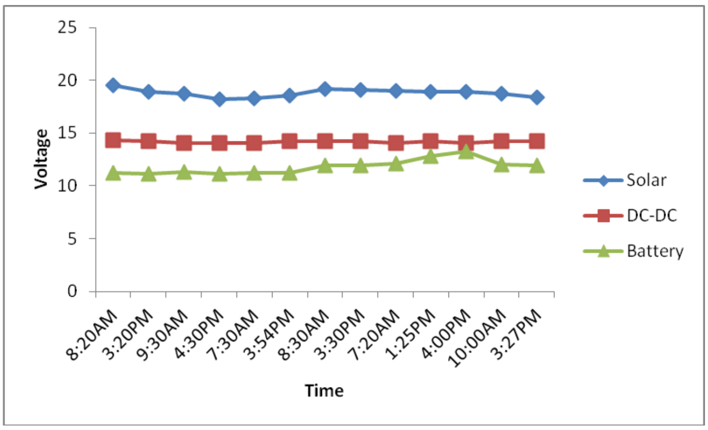

Fig. 8. Voltage and time relationship for the photovoltaic panel, DC/DC converter, and battery storage.

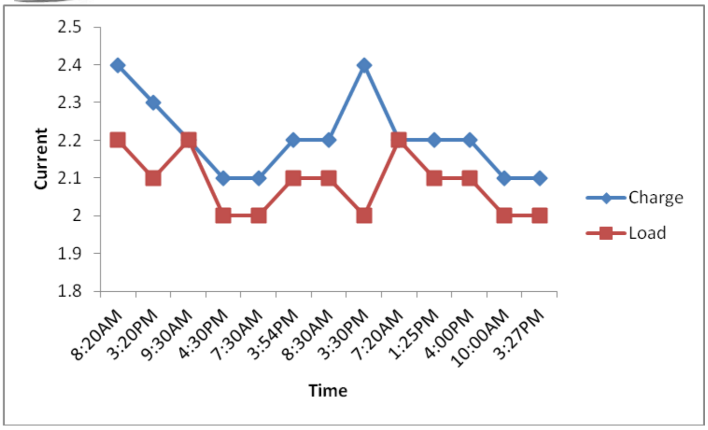

Fig. 9. Charging current and load current relationship vs time.

The data gathered and average values on each of the measured parameters are shown in table 1. In this case, the solar voltage had an average value of 18.8 V, the DC/DC converter had an average value of 14.2 V, the battery voltage had an average value of 11.8 V, the charging current of the battery had an average value of 2.2 A, the load current had an average value of 2.1 A, and the DC/AC converter had an average value of 158.6 V. Figure 8 shows a graph that compares the voltages observed from the photo voltaic panel, DC/DC converter, and the battery voltage with respect to time. Also, figure 9 shows a graph of comparison between the charging current and the load current with respect to time.

IV. Conclusion

A clean renewable source of energy is a challenging problem for electrical and electronic devices nowadays to provide uninterrupted electric power supply for continuous operation. This paper has presented a novel design and implementation of fuzzy logic control based grid tied uninterruptible power supply integrating environment friendly renewable solar energy. The proposed system utilizes the clean source of energy, which is solar and converts to electrical energy to facilitate the charging operation of the battery through the DC/DC converter and generates a constant active uninterruptible power supply to the load under normal runtime operating conditions. The system through fuzzy logic control automatically configures to utility AC in the absence of solar energy for storage demand in charging the battery and providing uninterruptible power supply to the dynamic load. The fuzzy logic control based grid tied uninterruptible power supply integrating with the renewable solar energy has been designed and implemented in a complete hardware prototype model. Experimental studies have been performed and carried out for the design and implementation of fuzzy logic control based grid tied uninterruptible power supply integrating renewable solar energy to test and evaluate the performance of the constructed prototype. Results have clearly confirmed that the constructed prototype is remarkably effective as uninterruptible power supply and recharging the battery. It significantly provides a smooth and continuous power supply to the electrical load being served with. The sustaining operation of the constructed prototype which can help then to remain in the service to continuously provide the uninterruptible power supply, especially for the life support electrical and electronic devices without impairing the environment. The system is less complex, effective, sustainable, feasible, and environment friendly (waste free) technology. The system can be easily used as uninterrupted power supply (UPS) for the electrical and electronic devices.

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