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Development of Micro-Controlled Multi-Powered Uninterruptible Power Supply System

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Abstract **– This paper discusses the design and prototype implementation of a multi-powered uninterruptible power supply system using a microcontroller. The system consisted of three basic units: the battery charging unit, the automatic switching unit and the inverter unit. The battery charging unit has components such as AC power, solar panel, a battery and the charging circuitry. The automatic switching unit includes the micro-controller and MOSFET switches to regulate the charging from multiple sources as well as switching from the power supply from AC to battery and vice versa. The inverter unit includes the transformers and other power electronic components to convert DC to AC power. Voltage and current measurement of our power supply output indicate optimal performance within expectation. Also, the battery charged faster with AC than solar power. We intend to further explore the use of miniaturized components to make the entire system smaller.**

Keywords **– Inverter, Micro-controller, Solar energy, MOSFET switches, Electrical Power.**

I. Introduction

The field of electrical power has witnessed tremendous development in recent years. The advent of new power controlled devices has contributed significantly to an enhanced performance of the existing power converters. The birth of innovative converter/inverter topologies has paved the way for further improvement in the overall power quality [1].

Multilevel inverter has gained much attention and became more popular now a day due its high quality output waveforms, low switching losses and high voltage capability, less EMI and reduced harmonics [13][14][16]. Using multilevel inverters specific harmonics can be eliminated in order to generate less distorted sinusoidal waveform. Multilevel inverters can be used medium voltage to high voltage range applications. It covers wide range areas including Uninterruptible Power Supplies (UPS), DC power source utilization, induction heating, high power motor drives, HVDC power transmission, electric vehicle drives, power distribution etc.

The design and implementation of a multi-powered (AC and solar) uninterruptible power supply system (UPS) is explained. Section II reviews related works in the field of electrical energy generation and conversion, power electronics and inverter designs. Details of the methodology used in the UPS design and implementation are given in Section III while Section IV discusses our system evaluation. Section V concludes the paper with pointers to future work.

II. Related Work

A designed photovoltaic (PV) module for generating electrical power by converting solar radiation into direct current electricity using semiconductors was proposed [12]. Photovoltaic power generation employs solar panels composed of a number of solar cells containing a photovoltaic material. The designed module was used in building an inverter system. Similarly, [2] [5] [8] developed an inverter with automatic voltage regulation (AVR) using switch mode square wave switching scheme. An inverter is an electrical device that converts direct current (DC) to alternating current (AC). The resulting AC can be at any required voltage and frequency with the use of appropriate transformers, switching, and control units [3] [4]

A new voltage control method was proposed for single-phase full-bridge PWM inverters [6][7] The proposed voltage controller has capability to realize a zero steady-state output voltage error with fast response without complicated transformation. To control the output voltage, a voltage control based on new virtual LC resonant circuit is proposed. By using the proposed control technique, a zero steady-state error can be achieved. In order to improve the output voltage response, a virtual resistor is connected in parallel with the output filter capacitor. Experimental results showed that the output voltage of a single-phase PWM inverter can be controlled faster and accurately even under nonlinear loads.

A comparison between Diode Clamped and H-Bridge Multilevel Inverter (5 to 15 odd levels) has also been previously carried out [6]. Multilevel converters are increasingly being considered for high power applications because of their ability to operate at higher output voltages while producing lower levels of harmonic components in the switched output voltages. One of the major problems in electric power quality is the harmonic contents. There are several methods of indicating the quantity of harmonic contents. The most widely used measure is the total harmonic distortion (THD) [9] [10]. The authors compared the various multilevel circuits (diode clamped and H-Bridge) with SPWM strategies. Operating principles with switching functions are analyzed for Five to Fifteen (odd) levels SPWM inverter to alleviate harmonic components of output voltage. Simulated experiments were carried out using MATLAB Simulink.

III. Design and Implementation

The UPS system was designed with three basic units as shown in Fig 1. The UPS has two sources of energy: solar energy and AC electrical power to charge the built-in battery of the UPS. The charging used in this design is the constant voltage method, which means that a constant voltage source is applied to the battery, as the battery gets charged the current supplied to it reduces [11]. The system employs an automatic transfer switch in switching its operation from the AC mains to the inverter power and vice versa. This inverter circuitry uses a regulated pulse width modulated signal to generate oscillating signals in order to control the switching on and off of the power MOSFET which are connected in parallel to a centre-tapped transformer. The MOSFET switches the 12V DC from the battery across the windings of a 50Hz for the use of domestic appliances with maximum power rating of 1000VA.

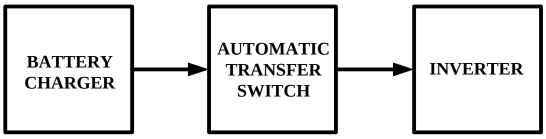

Fig.1. Basic units of the multi-powered UPS

Some components of the multi-powered UPS are discussed in the following sub-sections.

A. Inverter Design

The components of the inverter are shown in Fig. 2. A 100AH battery was used as it was adequate for the 1KVA maximum load. The microcontroller used was PIC16F876A because of its large program memory, I/O ports and analogue/digital channels [12]. The buffer amplifier, which is viewed as part of the microcontroller unit in this work, consists of two NPN transistors (2SC1815) connected in the emitter-follower mode. The microcontroller outputs complimentary PWM signals trigger these transistors into saturation. Voltages from the emitter of the two NPN transistors are used for driving the gates of the MOSFETs and are triggered into operation alternatively for the same period of time.

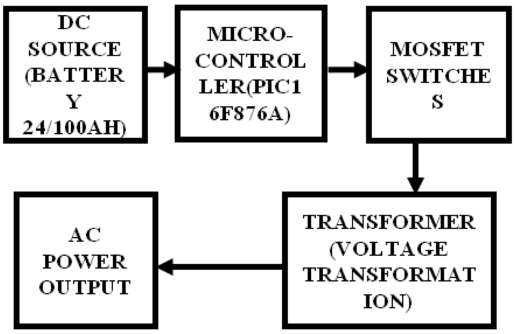

Fig. 2: Components of the Inverter

As a result, current through the primary becomes alternating due to the alternating current provided at each half cycle across the center-tapped transformer. This induces an AC voltage across the secondary and hence, across the load. The selected MOSFETs have a drain-to-source breakdown voltage higher than 12V since MOSFETs must be able to handle more than twice the battery voltage.

The MOSFETs were designed with a peak drain current of 95A. Ten MOSFETs are used in parallel to reduce the current drawn from each MOSFET to about 52A. Four NPN MOSFET IRF3205 with V_{BRDSS} of 55V and I_d of 110Amps were used for each tapping of the transformer's primary winding. . The total power dissipation of each MOSFET at maximum power rating of the inverter is 1.8Watts which meets the MOSFET IRF3205 maximum power dissipation of 20Watts. The MOSFETs were also mounted on a large heat sink to reduce heat loss. A limiting resistor of 20ohms is used between the buffer amplifier and the gate of each MOSFET.

One of the most important part of an Inverter is the transformer. The selected transformer in our work has a maximum power (Pmax) of 1000VA, input voltage (Vin) of 12V DC, output voltage (Vout) of 220V AC, and frequency of 50Hz.

B. Automatic Transfer Switch

The inverter live wire and the 24V battery are connected in a normally close (NC) configuration while the AC mains and the charger circuit are connected in normally open (NO) configuration of the relay. When there is AC supply, the switch will be at NO (normally open) position of the automatic change-over switch thereby supplying the outlet socket. Then, the charger will keep on charging the battery till the battery is fully charged. When there is power failure from the AC supply, the relay moves from NO to NC position making the inverter to switch on.

C. Battery Charger

The charging used in this work is the constant voltage method, where a constant voltage source is applied to the battery, as the battery gets charged the current supplied to it reduces. The charging unit uses the same inverter transformer and the intrinsic diodes of the MOSFET connected in full bridge mode for charging. When there is presence of AC power, the switchover connects the transformer to the 220V AC from the utility power. This results in 24V AC on the primary side of the transformer. The 24V AC is rectified into 24V DC with the internal diode of the MOSFET. These diodes are rated to have a forward current (I_f) which is equal to the drain current (I_d) of the MOSFET, whereby the drain current of each MOSFET is about 110Amps.

The conversion from DC to AC from the battery source is done by the microcontroller where 16 and 17 pin were program to monitor the conversion from DC to AC signal. The analog signal coming into the microcontroller with the aid of the embedded component within the microcontroller converts it to digital signal in which the output of the pins is connected to the MOSFET which amplify the signal to be used by the system.

D. Operating Status Display

The operating status display was implemented using the HD44780 based 16x2 alphanumeric liquid crystal display (LCD). All HD44780 based character LCD displays are connected through 14 pins: 8 data pins (D0-D7), 3 control pins (RS, E, R/W), and three power lines (V_{dd}, V_{ss}, V_{ee}). The control pin RS determines if the data transfer between the LCD module and an external microcontroller are actual character data or command/status. When the microcontroller needs to send commands to LCD or to read the LCD status, it must be pulled low. Similarly, this must be pulled high if character data is to be sent to and from the LCD module.

The direction of data transfer is controlled by the R/W pin. If it is pulled Low, the commands or character data is written to the LCD module. And, when it is pulled high, the character data or status information from the LCD registers is read. In our design, one way data transfer, i.e., from microcontroller to LCD module, is used so the R/W pin will be grounded permanently. The enable pin (E) initiates the actual data transfer. When writing to the LCD display, the data is transferred only on the high to low transition of the E pin.

Although most of the LCD module data sheets recommend +5V d.c. supply for operation, some LCDs may work well for a wider range (3.0 to 5.5 V). The V_{dd} pin should be connected to the positive power supply and V_{ss} to ground. Pin 3 is V_{ee}, which is used to adjust the contrast of the display. In most of the cases, this pin is connected to a voltage between 0 and 2V by using a preset potentiometer.

Pins 7 to 14 are data lines (D0-D7). Data transfer to and from the display can be achieved either in 8-bit or 4-bit mode. The 8-bit mode uses all eight data lines to transfer a byte, whereas, in a 4-bit mode, a byte is transferred as two 4-bit nibbles. In the later case, only the upper 4 data lines (D4-D7) are used. This technique is beneficial as this saves 4 input/output pins of microcontroller. In our design, the 4-bit mode is used.

E. System Implementation

The construction of the 1KVA, 220volt, 50Hz and 50% duty cycle was a gradual process of selecting materials. All the components were initially tested followed by temporary construction of prototype on bread board before transferring to the Vero board. All the components was tested and properly inserted in the Vero board with care. The circuit was constructed based on the design in units. Then, all the unit circuitries were joined together.

The MOSFET used in the driver circuit were mounted on heat sink, which is thick enough to absorb any heat generated. Each circuit board was screwed with bolt and the rubber sleeve to prevent electrical shock and then enclosed inside a metal portable metal casing. Both electrical and mechanical tools were used for the construction including driving machines, screw driver, pliers, soldering-iron and paper-tape.

The circuit boards from the units namely oscillator, changeover, display and regulator boards, as well as transformers for inverter, charger and changeover were coupled together to determine the dimension of casing needed. The casing size was chosen to contain the boards tightly but with space for air ventilation. Metal sheet was used for constructing the UPS casing with and electric drilling machines used in the drilling of holes to fit the boards and the transformers within the casing.

IV. System Evaluation

The evaluation was done using voltmeter and ammeter to compare the charging rate of the battery when using the solar power source or the AC mains at different time intervals. The functionality of the UPS system was carried out using a digital multi-meter to vary the current value and the voltage value during different specific times. A rated maximum power of 1000W was obtained. Current at maximum power equals 5.81A with a corresponding voltage of 17.2A. Short circuit current and open circuit voltage of 6.46A and 21.6v were also obtained.

Charging with the solar power, it was observed that the maximum charging voltage was obtained when the sun's intensity was highest between 2:00pm to 4:30pm. The battery voltage before charging was 10.20 volts, with an average charging current of 5.53A. After about 6 hours, the battery voltage (measured) was 12.57 volts. Details of our measurements are shown in Table 1.

For AC mains supply for charging, it was observed that the voltage before charging was 10.70 volts, then after about 4 hours, the battery voltage measured was 13.75volts. Details of our measurements for charging with AC mains are shown in Table 2.This indicates that charging the battery with AC power works faster than charging with solar power. Also, AC mains charges the battery to its fullest level unlike the solar power where the charging rate level for battery reduces as sun goes down.

Table 1: Measurements with Solar power charging

S/No	Time	Charging Voltage	Charging Current
1	10:00am	14.0	2.89A
2	10:30am	14.3	3.20A
3	11:00am	14.6	3.26A
4	11:30am	14.6	3.25A
5	12:00pm	15.2	5.45A
6	12:30pm	15.5	5.57A
7	1:00pm	16.8	5.68A
8	1:30pm	16.1	5.81A
9	2:00pm	17.0	5.81A
10	2:30pm	17.0	5.80A
11	3:00pm	17.0	5.81A
12	3:30pm	17.2	5.79A
13	4:00pm	17.1	5.78A
14	4:30pm	17.1	5.81A
15	5:00pm	16.1	5.79A
16	5:30pm	15.5	3.30A
17	6:00pm	11.6	1.80A
18	6:30pm	6.2	1.32A
19	7:00pm	3.2	0.32A

Table 2: Measurements with AC power charging

S/No	Time	Charging Voltage	Charging Current
1	10:00am	10.70	12.0A
2	10:30am	10.75	11.8A
3	11:00am	10.95	11.5A
4	11:30am	11.25	10.2A
5	12:00pm	11.65	9.5A
6	12:30pm	11.95	8.2A
7	1:00pm	12.35	6.8A
8	1:30pm	12.95	4.0A
9	2:00pm	13.25	2.5A
10	2:30pm	13.75	1.0A

V. Conclusion

This paper has discussed the design and prototype implementation of a multi-powered uninterruptible power supply system using a microcontroller. The system consisted of three basic units: the battery charging unit, the automatic switching unit and the inverter unit. The efficiency of the system depends on the power efficiency of the transformer and oscillator circuit used. The duration of working of this inverter depends on the type of the battery used and power of the load consumed at a particular time.

Evaluation showed that charging the battery with AC power was much faster than with solar power. We intend to extend the work by adding other sources of electrical power to charge the battery, especially at night when there is no solar power.

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