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Smart Battery Management System Using LiFePO4 Battery for Offline UPS

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Smart Battery Management System Using LiFePO4 Battery for Offline UPS

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Abstract. Power integrated circuits (ICs) have developed solutions for charging systems and power management system for battery powered devices. The main purpose of a battery management system comprises handling the charging cycle to limit the charging time without focusing on the battery. It also monitors the present status of the battery and reports the fault conditions if any malfunction or error occurs. This system is based on a smart LiFePO4 battery for offline UPS, which is used to power up a home AC application with 230VAC/50Hz. The main reason to select the LiFePO4 battery life cycle, it is made up of non-toxic material and this battery is not overheated or catches fire in case of overcharging or overload. In this system, the Arduino UNO microcontroller is used and it takes care of the parameters like battery charging voltage, charging current, and high voltage cutoff at backup mode. It also monitors the battery voltage, battery current, low voltage cutoff, and overload protection at inverter mode.

Key words: Uninterruptible Power Supply, LiFePO4 Battery, Direct Current, Alternating Current, Pulse Width Modulation.

1. Introduction

The main kinds of static UPS frameworks systems are on-line, off-line, and line-interactive arrangements. This system uses a LiFePO4 battery to store energy for backup power in offline UPS. Offline UPS works in two modes of operations. First “Inverter Mode” and another one is “Backup Mode”. The microcontroller continuously monitors the grid power is present or not. When grid power is not present, then UPS goes to inverter mode. When grid power is present, then UPS goes to Backup Mode. In inverter mode, UPS converts the DC component in the battery into the AC component. Then UPS continuously monitors the grid power is present or not and it monitors battery voltage, battery current, and load capacity. This model consists of an oscillator circuit, a MOSFET driver circuit, step-up transformer, battery’s low voltage cutoff, and overload protection circuit [1].

In the presence of grid power, then the micro-controller switches UPS into Backup mode. It converts the AC components from the grid into DC component for charging the battery. UPS monitor the battery charging voltage, charging current and switch grid power to load. Uninterruptible Power Supply is represented as UPS in short. UPS is an independent substitute power source that is used to source various sensitive electronic loads such as computers, medical assistance, communication exchanges, and many control and monitoring units in industries. Such type of application needs a power source that is always available in good quality.

A UPS is a solution for providing a good power source interface between the utility and the sensitive loads. The UPS will provide the voltage that is:

- Free from the disorders present in utility power and consistent with the required tolerances level by loads.
- Available in the event of utility blackout, within stated tolerances

UPS fulfill the above conditions as of power accessibility and quality by:

- Providing the voltage fulfilling with strict tolerances to the load, using an inverter
- Providing a self-governing alternate source, using a battery
- Change to alternate utility power with no handover time. i.e. without any interruption in the power to the load.

The above conditions make the UPS system an ideal power source for all sensitive loads since they guarantee the availability and good quality source, irrespective of the condition of the utility source power.

Basic Parts of a UPS System includes the following main components:

- Rectifier which converts AC to DC power to charge a battery.
- An Inverter that produces high-class electric power free from all the disturbances, particularly from micro-outages which within the tolerances level of sensitive electronic devices.
- A Battery, that delivers adequate backup to ensure the safety of the sensitive devices.
- A semiconductor-based static switch that switches the load back and forth from the inverter and utility power.

Different kinds of static UPS were characterized by standard IEC62040. The three operating modes for UPS are

- Offline - Passive standby
- Line-interactive
- Online - Double conversion

Leo Louis [2] presents Arduino boards can be a good tool in developing VLSI test bench, particularly for sensors. The main benefits are rapid processing and a simple interface. The author expressed the use of open source software and hardware devices in the present technological world. Creating and implementing new designs with Arduino becomes endless. Arduino can be used from wearable fashion to space research. Zhen Zhu et al [1] presented a technique for instantaneously increase the quality and efficiency of power for marine distributed generation. To limit the pollution treatment of external power, the self-regulatory capacity of the output voltage was enhanced by PI guidelines and the real-time feedback method. The efficiency of power conversion was improved by 10%. Pulse width modulation (PWM) is used in the control circuit for a single phase inverter by Omokere, E. S et al [3]. The 3525A controller is used to create the essential waveforms to control the frequency of the inverter using the switching pulse. The DC to AC inversion was effectively achieved by the switching signals; the inverter output has a frequency of almost 50Hz. Hence the conversion of DC to AC was successful. Michal Knapczykf. et al [4] analyzed the modulation schemes for the AC/DC line-side converters. The modulation techniques are mainly responsible for the process of the AC/DC converter. The problems in the over modulations were analyzed.

Chosen modulation methods were examined by using Voltage Oriented Control of the AC/DC line-side converter. Switching frequency and line current distortion were also studied. Power inverters operate under dynamic loads were examined by F. Onoroh et al [5]; their aim is to make a thermal model to the IRF 3205 MOSFET chip switching operation and is realized in MATLAB R2013a setting to get the transient temperature response. The simulation demonstrates that exponential build up function is shown for transient device temperatures profile and rapidly increases till it attains the steady state during the switching operation. A set of equations were used for determining the switching losses of an IGBT device in an electromagnetic transient program and were integrated into the power electronic switching model. A.D. Rajapakse, et al [6]. Formulae were derived for estimating the switching losses during turn-on and turn-off by using predicted trajectories of the device between their pre and post switching-values.

Danijel Pavković et al [7] designed a cascade control system for a battery constant-current constant-voltage (CCCV) charger which has voltage PI controllers and dedicated battery current. Damping optimum criterion is used for designing the controller. LiFePO4 and VRLA battery cells were taken for testing. Superimposed voltage controller and inner current controller were implemented for the CCCV battery charging. Daniel Akinyele et al [8] analyzed the dependability of battery based on loss of power probability (LOPP) and the cost of energy (COE), by the life cycle cost study. The Hybrid Optimization Model was used to simulate battery banks for Electric Renewables (HOMER) environment. The results validate that the LOPP reduces with an increase in battery cells and the COE raises with the increase in the battery cells. Elie Ayoub et al [9] analyzed different charging techniques which are acceptable for commercial battery chargers and they have given the boost charging method as the appropriate charging method for recharging the battery. Christian Brañas et al designed a resonant converter based battery charger for high power $LiFePO_4$ Batteries. A model for charging a 48 V LiFePO4 battery with 50 Ah of capacity is designed and achieved a very good efficiency [10].

2. Implementation

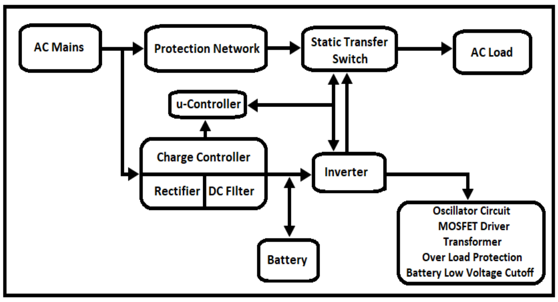

Figure 1. Block Diagram

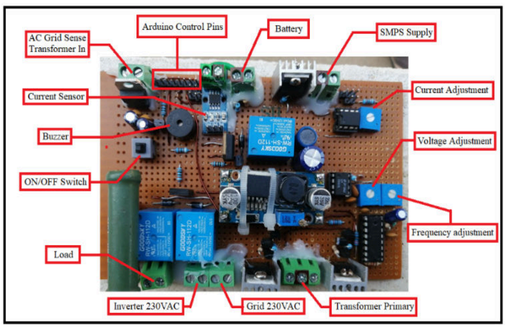

Figure 2. Top View

Figure 3. Practical View

3. Inverter Mode

When grid power is not present, then UPS goes to Inverter Mode. UPS converts DC power in the battery into AC power. UPS continuously monitors the grid power is present or not and UPS monitors battery voltage, battery current, and load capacity [11]. The inverter mode consists of an oscillator circuit, a MOSFET driver circuit, a step up transformer, a battery, a low voltage cutoff, and an overload protection circuit.

3.1 Oscillator

In India, the EB voltage is 220 volts with a 50 Hz frequency. Therefore, the inverter output is ~220VAC/50Hz. Transformer works only in AC [12]. Here SG3525 IC used to generate a 50Hz PWM signal for oscillates the MOSFET to convert the DC component of the battery into pulsated DC component.

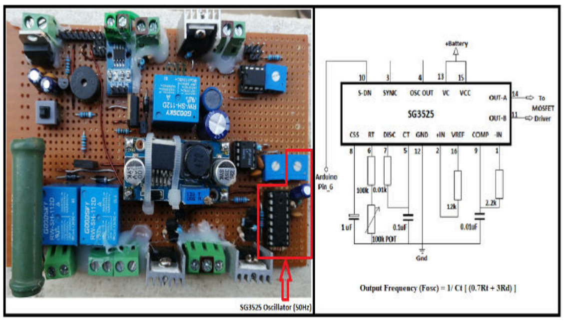

Figure 1. SG3525 Oscillator

3.2 MOSFET Driver

Here MOSFET act as a switch to drive the DC component of the battery into pulsated DC based on the oscillation frequency. IRF3205 MOSFET, which can drive continuous 110A of current. This MOSFET have very low R_{DS} resistance in the range of milliohms [13].

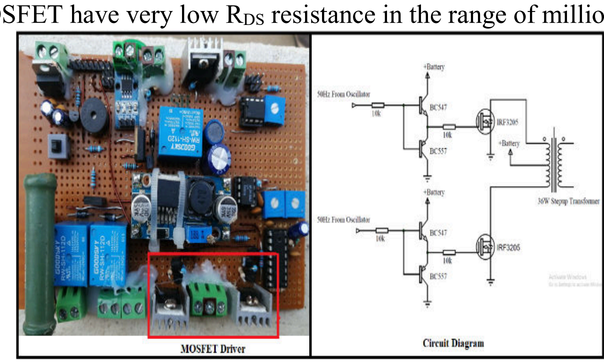

Figure 5. IRF3205 MOSFET Driver

3.3 StepUp Transformer

This transformer and MOSFET driver determine the load capacity. Here 12-0-12 EI core 3A transformer used to convert low voltage AC into high voltage AC. So it can load up to 36W (max). Due to the efficiency of the UPS, overload protection set to the maximum of 20W load at the output terminal.

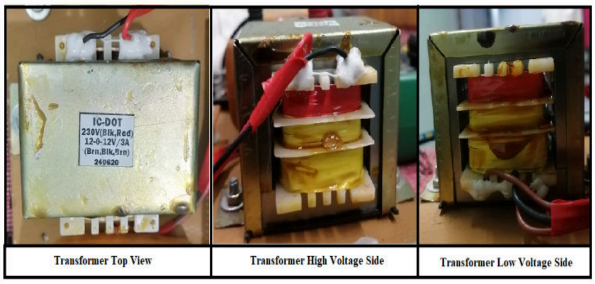

Figure 6. Power Transformer (36W)

3.4 Output Voltage Adjustment

IC555 circuit is used to control the PWM signals applied to the gate of the MOSFETs driver circuit. This PWM adjustment can affect the energy transformation between the primary and secondary of the transformer [4] [14]. This way we can adjust the output voltage to control the ON-Time of the PWM signal applied to the gate of the MOSFETs.

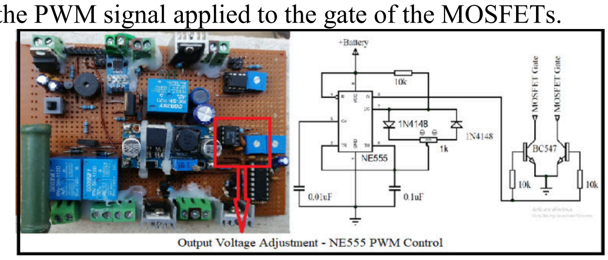

Figure 7. Output Voltage Adjustment

4. Operation

4.1 Inverter ON/OFF

Inverter ON/OFF state is controlled by ON/OFF state of an external switch. If the switch is ON, then the inverter is ON and vice versa. Microcontroller updates the status of inverter in the LCD display.

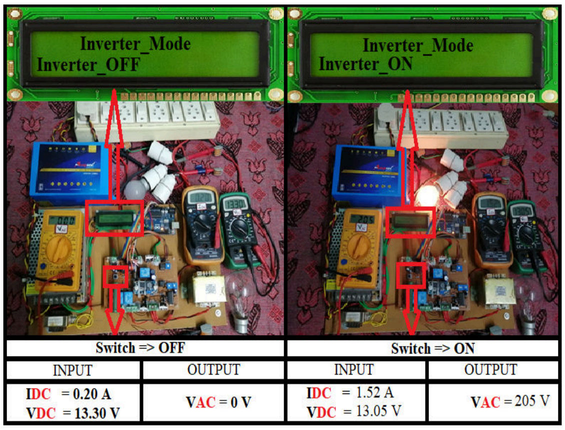

Figure 8. Inverter ON/OFF Control

4.2 Overload Protection

When connecting more loads to UPS the transformer drain more current from the battery.

The microcontroller monitors the battery current with the help of the ACS712 Hall-effect based current sensor. If the transformer drains more current, then the controller switches off the inverter as well as indicates overload in LCD display.

4.3 Battery Low Voltage Cutoff
If the power cut is too long, then the battery drains too much. This may cause damage to the battery permanently. So, cut off the battery at recommended voltage level. The microcontroller monitors the battery voltage and switches off the inverter if the voltage level of the battery is less than the recommended voltage level.

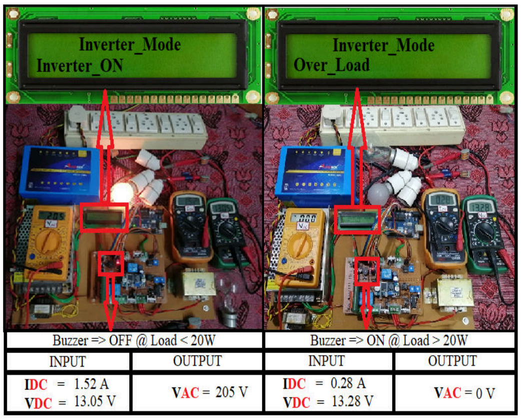

Figure 9. Overload Protection

5. Backup Mode
Grid power is present, then the UPS switch Backup mode. It converts the AC component from the grid into the DC components for charging the battery. UPS monitor the battery charging voltage, charging current and switch grid power to load.

5.1 Charging Voltage & Charging Current Control Circuit
Microcontroller monitors battery voltage and the current entering or leaving the battery. Charge control circuit controls the charging voltage, charging current, and battery overvoltage cutoff. Microcontroller takes care of all these things [15] [16].

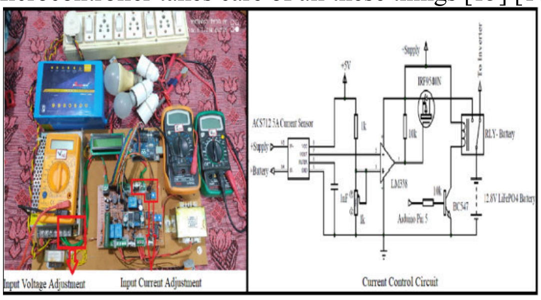

Figure 10. Charging Voltage & Charging Current Control Circuit

5.2 Power Switching
When the micro-controller sense grid power is present, then it monitors battery charging voltage and charging current as well as switches grid power to load with help of a relay circuit. The controller switches relay circuits to bypass grid power to load and at the same time battery charges with help of grid power [17].

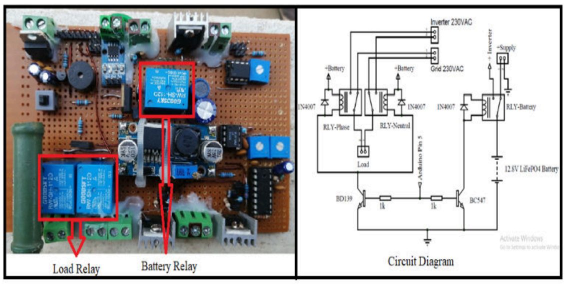

Figure 11. Power Switching

6. Microcontroller

Arduino UNO R3 micro-controller is a heart of this project. It switches the UPS into either backup mode or inverter mode based on the grid power. This monitors the output voltage, output current, and load capacity at inverter mode. In addition, it monitors charging voltage, charging current, and switch grid power to load at backup mode. Moreover, it controls the 16*2 LCD display via I2C communication for display UPS status.

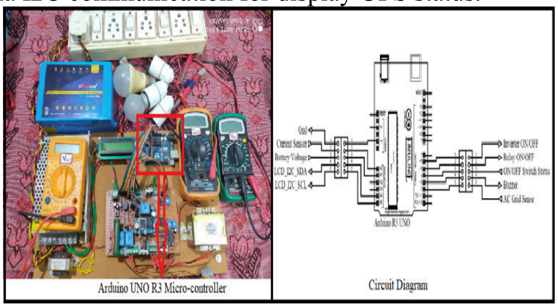

Figure 12. Arduino UNO R3 Microcontroller

7. Battery

A 12.8V 18Ah 0.5C LiFePO4 battery is used in this project. Table 1 shows the advantages of the LiFePO4 battery over the lead acid battery, SLA battery, and Li-ion battery [9]. LiFePO4 battery made up of non-toxic materials and battery not overheated or catches fire in case of overcharge or overload [14].

Table 1 Features of LiFePO4 Battery

Features	Lead Acid	Li-ion	LiFePO4
Efficiency	70%	80-90%	80-95%
Charging & Discharging Current Rate	0.1C	1C(max)	10C
Life Cycle	500-1000	1500-2000	2000-10,000

8. Features

8.1 Battery

- Battery Life cycle
- Non-toxic material
- Efficiency
- Very minimum space to store
- Less Charging and Discharging time when compared to lead acid and SLA batteries.
- Battery not overheated or catches fire in case of overcharge or overload.

8.2 Inverter

- Configurable output Voltage and Frequency
- Overload protection
- Over current protection

- Battery low voltage cut off

8.3 Charge Circuit
- Short circuit protection
- Battery over voltage protection
- Charging voltage control
- Charging current control

9. Application
- Industries
- Data Centers
- Banks and insurance
- Hospitals
- Telecommunications
- Some special projects (events)

10. Things to Improve

10.1 Inverter Output Voltage (V_{AC})

This project did not have a feedback circuit. Therefore, the output voltage changes with respect to load. In addition, battery voltage is near to transformer's operating voltage. After connecting load, output voltage decrease with respect to load. At that time, 100% duty cycle PWM pulses for MOSFET drives are not enough to increase the output voltage. Therefore, the selected transformer operating voltage is less than the battery voltage.

10.2 Inverter Output Waveform

Starting this project design was a pure sine wave inverter. But a square wave inverter was designed due to some practical issues. Therefore, the next improvement is converting this design into a pure sine wave inverter design.

11. Conclusion
Now a day, most UPS use lead acid or SLA batteries and few UPS use Li-ion batteries. But, another battery technology has much more advantage when compared to all the above batteries that are the LiFePO4 battery. The main objective of this project is a perfect battery that gives more reliability to the UPS. Because when compared to other batteries, LiFePO4 has a lot of advantages, especially battery life cycle, LiFePO4 battery is made up of non-toxic material and LiFePO4 battery is not overheated or catch fire in case of overcharging or overload. Other battery's UPS is not supported to LiFePO4 battery. Because the LiFePO4 battery's voltage rating and the current rating were different from each other.

Therefore, in this system, a UPS specially design for LiFePO4 battery's voltage rating and current rating. Other than that, features of UPS were added to this design. For example, in inverter mode overload protection, battery low voltage cutoff, and in backup mode overcharging cutoff are included in this design.

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