TI India Analog Design Contest 2012-2013

SELF ASSESSMENT

"We, authors of the report entitled **Solar Power based Intelligent Battery Charging system Compatible with existing Home Inverters,** confirm that this report has not been submitted to any other forum such as another contest or conference for publication. We hereby state that we will not submit the same work for any other contest in the future. We understand that Texas Instruments has the right to use this report in its conferences/publications. We will seek TI's permission before we submit the report for publication in an external forum."

Originality of the Idea

Our project idea is entirely original and is not the inspiration of any existing work. We were determined to do something to fight the power crisis situation we faced in our state - Tamil Nadu. Though existing solar-inverter systems are available in the market, they do not involve Power flow management. We also thought - why not use the solar energy itself to supply the required load demand when power is in surplus? This would also mean cutting down on our electricity bill. We included all these features in our project to develop an efficient and intelligent battery and power management system for existing home inverters.

Technical challenges faced

- One major technical challenge we faced was the damage of +12V linear voltage regulator (LM340T12) due to excessive heating. Since the PV input voltage is around 35V, the voltage drop of around 22V caused a lot of heating problems and hence frequent shutdown during operation. Replacing the LM340T12 by the switching voltage regulator (TL2575-12) solved this problem.

- Another technical challenge encountered was choosing a suitable gate driver IC. We initially used Quadruple Half-H driver IC L293D, however it was not fit for prolonged high frequency operation and it failed to fire the IGBT. IC UCC27322 was later used as the gate driver for the IGBT and it was reliable at high frequencies.

- Our system required a dual power supply for the current sensor to measure the battery charging and discharging current. Creating a negative power supply from a single source was a challenge. A complicated and big circuit using timers and voltage doublers gave a negative supply but it had voltage fluctuations and the charge pumps consumed a large current. But thanks to TI's Switched Capacitor Voltage Converter IC - LMC7660, which we were previously unaware of, we could easily obtain a negative supply -10 V from +10 V from this single small IC. Using this, the above problem was overcome.

Non-technical challenges faced

- One of the main non-technical difficulties we faced was the very same power crisis we wanted to overcome. Faced with 15 hours+ power shutdown per day, it was very difficult testing circuits and debugging components in the initial stage. We had to make efficient use of the little time in the day when we had both electricity and sufficient sunlight. Hence we made our system self-sustained by taking the required power from the solar panels itself. Once this was achieved, we no longer needed to be rely on external power from the mains. We only occasionally needed a DSO for troubleshooting.

- Another non-technical difficulty was procuring the inductor needed for our Buck converter. Readymade inductors were not available for the value of inductance we desired. Hence, we made an air-core inductor ourselves by winding copper wire on a bobbin for the required number of turns and the inductance value was cross-checked using a LCR meter.

Future Scope

The work is just one step behind short of a commercial product which can be widely used in homes. Replacing the MSP430F5438 Experimenter board (which was used in this work for easier debugging and demonstration purposes) by a low cost controller and using cheaper current sensing solutions instead of current transducers will make the product very much affordable. The size of PCBs when manufactured will be significantly reduced and can make this system more compact.

Implementing a Solar-Wind hybrid system to build a self-sustainable clean home is the future scope of this project. This idea requires further investments and considerable time to work on and we hope to pursue it in our future research.

Acknowledgements

Our mentor, Dr. G.Saravana Ilango was a constant source of strength and support to our project. Power Electronics was a completely new field to us and we could have definitely not completed the project without his valuable inputs. He also gave us a clear idea about the basics of Solar photovoltaics which happens to be his area of expertise and hence we could progress quickly without wasting much time with preliminary background research. He also helped us when we faced difficulties so that we did not stay stuck with the same problem. He constantly motivated us and made sure we completed the project on time and tested the system as a whole. We would also like to thank the research scholars Mr. C.K.Aravind and Mr.M.M.Rajan Singaravel for their valuable inputs and constant help throughout the project. Their suggestions helped us improve our design and bring the overall project to its final shape.

The TI India Analog Design Contest helped us in a lot of ways. We now have a clear theoretical and practical understanding of Solar photovoltaics, Power Electronics and many aspects of Analog Electronic circuits. We also gained a lot of experience in the field of Microcontrollers and PCB designing and application of various ICs. We gained a lot of interest in some areas of research like finding SoC of the battery, Solar Photovoltaics etc. The tremendous amount of competition meant we had to put in our best effort and it brought out the full potential in us. The deadlines made us disciplined and we trained ourselves to work systematically with targets. The contest also taught us teamwork- how to work effectively as a team and share the workload. On the whole, it was a great learning experience for us.

Aspects covered in the project

Paper design of hardware	☑	Algorithm/software design	☑
Hardware implementation on breadboard	☑	System-level testing with examples	☑
Hardware implementation on PCB	☑	Benchmarking/Performance Analysis	☐
Hardware Testing	☑	Short Video on Project **http://goo.gl/Y8hV5**	☑

Video link: **http://goo.gl/Y8hV5**

P. Dinesh　　B.Kowshick　　Pankaj Raghav.P　　Ramesh.K.Govindarajan

Dr.G.Saravana Ilango
(Faculty Mentor)

Solar Power Based Intelligent Battery Charging System Compatible with Existing Home Inverters

P.Dinesh*, B.Kowshick, Pankaj Raghav.P, Ramesh.K.Govindarajan
G.Saravana Ilango
National Institute of Technology
Tiruchirappalli, Tamilnadu, INDIA
*Email: 107110059@nitt.edu

Abstract*— PV modules are increasingly used in battery charging applications in home inverter systems due to the power crisis faced in developing countries. This work aims at maximizing the use of solar energy by charging the battery as well as by supplying it to the loads when in excess. This system is implemented using two subsystems namely a charge controller and a Power Flow Management System(PMS). The charge controller is used to control the power flow from the PV module to the battery by operating in two modes. The Maximum Power Point Tracking mode(MPPT) extracts maximum power from PV panels and the Voltage Control Mode prevents overcharging of the battery. A 160W prototype of the charge controller is simulated in MATLAB/Simulink environment and is implemented in hardware. The operation of the controller in the two modes is verified and the relevant results are presented. A PV system implemented in houses involves various power sources and sinks. A control strategy is formulated in the PMS to balance the power flow among these elements using State of charge (SoC) of the battery as the criterion.The SoC is determined using coulometric measurements and is periodically recalibrated using Open Circuit Voltage method. The PMS is implemented and verified using experimental results and the energy savings are presented.

I. Introduction

The main motivation of the project is from the increasing power cuts faced in the state as well as in many parts of the country. In recent times due to power cuts, most of the houses are now equipped with home inverters. However, there is not enough time to even charge the battery for sufficient power back-up due to the long hours of power cut. This calls for shifting towards alternative sources of energy which are clean and renewable. Among these, solar energy is widely used as it supports delocalized power generation.

While commercially existing solar chargers use solar power only to charge the battery, this work focuses on maximizing the usage of solar power. A power flow control strategy was earlier proposed for grid connected systems. A similar strategy is used to utilize the excess power by supplying it to the loads in a existing home inverter sytem. The main goal is to implement a subsystem without any modifications in the existing Inverter circuitry (plug and play system). Thus this system will help combat the energy crisis we face today and also will reduce the electricity bill incurred.

The report has been organized into 7 sections as follows: section 2 provides the comparison with previous works, section 3 provides the detailed explanation of the proposed system, section 4 shows the practical realization of the system in hardware with different ICs, section 5 presents the implementation of the various algorithms using flowcharts. Section 6 shows the the various experimental results and simulations performed to verify the system. The conclusions and future scope of the project are presented in Section 7.

II. Technical Background

The depletion of natural resources have led to the exploitation of other renewable sources of energy. Solar energy is sustainable and eco-friendly and Photovolataic panels can be easily installed at homes.

In developing countries like India, the demand for power is increasing and there are scheduled power outages. PV being intermittent in nature, energy storing devices such as batteries are integrated into the system to meet the dynamic power demands. A PV system implemented in houses involves two power sources (PV and utility), a power sink (load) and a power source/sink (battery), and hence a Power flow Management system(PMS) is required to balance the power flow among these sources. A PMS has been used to control the operation of the bidirectional converter in Grid Connected PV systems [1]. It can be argued that PV based Grid connected systems are more dominant. However in developing countries like India, net metering is a new concept and is still in the nascent stage. Hence the better option is to supply the power from the PV panels to the battery/local loads which also helps in solving the power crisis.

In the proposed system, the power flow control is achieved by switching the grid supply to the existing home inverter which inherently controls the power flow between the DC bus and the loads. The switching is done depending on the SoC of the battery as the criterion to effectively utilize the power from the PV

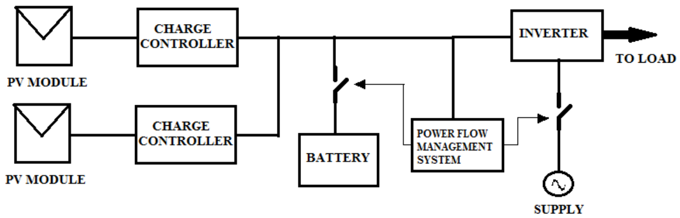

Fig. 1: Top Level Block Diagram

panels after sufficiently charging the battery. Thus the total energy consumption from the utility grid is reduced.

A power flow control strategy is implemented based on the terminal voltage of the battery in a Grid Connected PV system[1]. Battery voltage is not an accurate indication of the amount of electrical energy stored inside the battery [2]. A reliable and accurate measurement of the available charge or the State of Charge (SoC) of the battery is required to effectively implement the control strategy[3]. Coulometric measurement is one of the widely used methods for estimation of SoC. This method suffers from setbacks like accumulation of errors due to erroneous current measurements, charging and discharging efficiencies and self-discharge of the battery which are not accounted [2], [4]. Open circuit voltage(OCV) of the battery has a linear relationship with SoC but its measurement needs a long rest time and hence is not practically feasible in real time applications. The rest period for the OCV method can be reduced by predicting the voltage using the stabilization characteristics [5]. So a combination of both OCV and Coulomb counting is required to cover the weakness of both techniques and deliver an accurate monitoring system [5]. Thus the proposed system uses both techniques to estimate the accurate SoC[5], [6]. The SoC of the battery during run time is calculated using Coulomb counting and it is re-calibrated periodically using OCV method.

The system uses a charge controller to balance the power flow between the PV panels and the battery under different load conditions. Its objectives are to extract the maximum power from the PV panels (MPPT mode) and to limit the battery voltage (Voltage Control mode) to prevent overcharging of the battery [7]. A top level block diagram of the system is shown in Fig. 1.

The drawback of commercially available solar battery chargers is that solar power is not extracted once the battery is sufficiently charged[8]. The proposed system ensures that this power is utilized by diverting it to the loads. Hence the the charge controller and the PMS together ensure that the available solar power is used effectively.

III. Proposed System

The proposed system is implemented by developing two subsystems which operate independently of each other. The main constraint is to implement the control strategy without modifying the existing inverter circuitry. The system utilizes a Power flow management system to manage the power flow between the DC bus and the AC loads.

A. Charge Controller System

The Charge controller controls the flow of charge from PV panels to the DC bus. The controller operates in two modes - MPPT mode and VOC mode and the battery voltage determines the mode of operation. The load demand occurs only when the inverter is switched ON and it supplies the local loads from the DC bus. The battery may charge or discharge depending on the PV power and load demand. If the battery voltage is below the reference limit, the MPPT mode is employed to extract the maximum power from the PV panels. If the load is heavy enough to cause discharge of the battery, the PV panel provides the maximum available power to the load and the rest is supplied by the battery.

If the battery voltage exceeds the reference limit, the Voltage Control mode is employed to prevent overcharging of the battery. The operating point of the PV panels is changed accordingly to obtain a constant output voltage at the battery terminals. The rate at which the battery continues to absorb charge or the current through the battery gradually slows down because the voltage is maintained constant. A voltage band is used to prevent shuttling between the two modes.

B. Power Flow Management System

This system manages the power flow between the DC bus and the loads.

1) Battery Monitoring System: The estimation of State of Charge of the battery is essential to efficiently and effectively implement the power flow control strategy. Coulometric measurement has been used to determine the SoC during runtime of the battery. This involves counting of charge or Ampere hours entering or leaving the battery.

$$SoC = SoC_{init} + \frac{1}{C}\int idt \tag{1}$$

Since this method is accurate only for short term measurements, a method is required to recalibrate the SoC at regular intervals. Open Circuit voltage (OCV) of sealed lead-acid battery has linear relationship with SoC. The determination of OCV requires the battery to be disconnected from the loads along with long rest periods to stabilise the battery voltage. Hence continuous measurements of SoC cannot be done without disconnecting

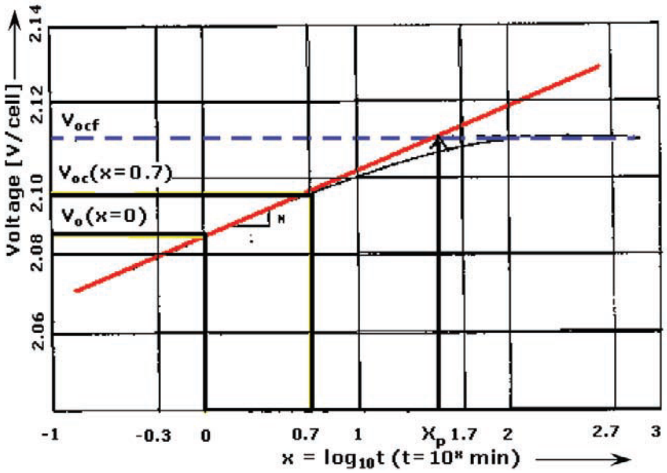

Fig. 2: Recovery characteristics of Battery Voltage after disconnecting from circuit [2], [5]

the loads. The rest period required for finding the OCV can be significantly reduced by predicting it using the recovery characteristics as proposed by Aylor[5]. A typical recovery characteristic of a battery when disconnected from the loads is shown in Fig. 2. The OCV can be obtained as follows:

$$V_{oc} = M \times X_p + V_0 \tag{2}$$

where,
Xp = value of X=log(t) at the intersection,
M is the slope of first asymptote and is calculated as

$$M = \frac{V_{0.7} - V_0}{0.7} \tag{3}$$

$V_{0.7}$ is the voltage reading taken at t=5 min (log5=0.7),
V_0 is the voltage reading taken at t=1min (log1=0).

The value of Xp is quite consistent for different SoC and different types of battery and is taken as 1.64. The above OCV method is used to recalibrate the SoC at regular intervals and it reduces the error accumulated in the coulomb counting process.

2) Power Flow Control: The commercially available inverters which are installed in homes operate in Inverter mode when there is no power supply and in rectifier mode to charge the battery. The control of power flow between the DC bus and the AC loads is achieved by switching the power supply from the mains to the home inverter using a relay. Switching OFF the power supply causes the converter to operate in Inverter mode, whereas the converter operates as a rectifier if switch is in ON state. The control strategy uses the SoC of the battery and previous state of the switch to determine the present state. This strategy is used only in the day time to effectively utilize the PV power. The state of the switch as per the control strategy is depicted in a state diagram shown in Fig. 3.

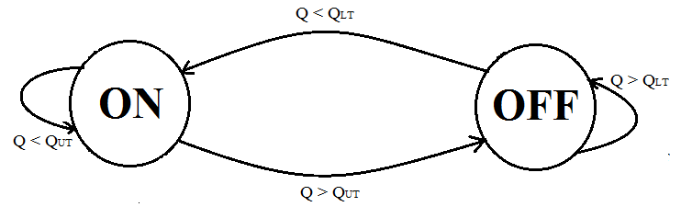

Fig. 3: State Diagram of the Control Strategy

A two level threshold limit of SoC is used for the control strategy. The upper threshold charge (Q_{UT}) corresponds to a level beyond which the switch is always set to OFF state to supply the excess power to the loads. The lower threshold charge Q_{LT} corresponds to a minimum SoC that the battery has to maintain to prevent deep discharge. Below Q_{LT}, the switch is always in the ON state. When the SoC is in between these threshold limits, the previous state of the switch is maintained. The switching from ON to OFF and from OFF to ON occur only at the upper and lower thresholds respectively, thus preventing repeated shuttling between two states even when the system is operating near the threshold levels.

C. Analog Subsystem

All the physical quantities to be sensed are analog in nature. The proposed system requires an accurate sensing and signal conditioning system to realize the physical quantities and to achieve proper control of the entire system. In order to build an independent system, the power supplies for the system components have been derived from PV panels or the battery thus requiring a voltage regulation unit.

1) Sensing unit: The sensing unit is used to convert the physically available voltage and current variables to appropriate signals which can be processed. The PV panel and battery voltages are sensed using operational amplifier circuits. Hall Effect sensors along with buffers are used for current measurement. Level shifters are used to obtain the required range. The presence of power in utility mains is monitored using a power sensing circuit.

2) Signal Conditioning Unit: The current output from the battery has extraneous frequency components due to introduction of power electronic devices, thus requiring a filter circuit to obtain a smooth DC signal which can be processed easily. The inherent noises from the sensors and voltage ripples in the voltage regulators are eliminated using RC filter circuits.

3) Voltage Regulation Unit: Since the system does not require an external power supply which is an inherent advantage of the system, linear and switching voltage regulators are used to step down the voltage to appropriate levels. Since some circuits require

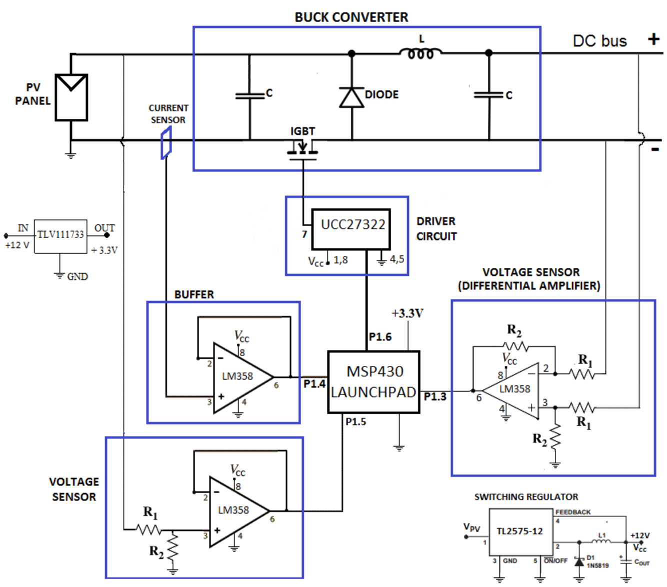

Fig. 4: Charge Controller Schematic

dual power supplies (+/-), switched capacitor voltage converter IC is used to obtain the negative voltage supply.

4) DC-DC converter: A Buck topology DC-DC converter has been used to implement the charge controller. It comprises a controlled switch, diode and LC filter. The LC filter is used to achieve a ripple free DC output. A gate driver IC is used to drive the switch using high frequency switching pulses generated by the controller.

IV. Hardware Implementation

The hardware components of the system include the sensors, voltage regulators, microcontrollers and DC-DC converter. Power PCBs are designed for the Charge controller system and PMS with proper ratings. The system is completely powered by the PV panel array and Inverter battery and does not require any other external power source. The voltage sensors are constructed with differential amplifier circuits using appropriate op-amps. All current sensor circuits utilize Hall Effect current sensors(LEM P/N. LA55P) followed by a buffer. The microcontrollers are powered from 3.3V supplies obtained via Linear voltage regulator (TI-P/N TLV111733).

A. Charge Controller Circuitry

The charge controller is a DC-DC Buck converter used to step down the voltage from PV panel to voltage at the DC Bus. The schematic of this circuit is shown in Fig. 4. The buck converter consists of a series switch and a LC filtering circuit, and is designed using the relations:

$$L = \frac{(V_{pv} - V_{battery}) \times D}{f \times 2\Delta i} \tag{4}$$

$$f = \frac{1}{2\Pi\sqrt{LC}} \tag{5}$$

IGBT (IRGPH50F) is used as the switch and the frequency of the gate pulse is fixed at 10 KHz and the change in current above and below the mean level (Δi) is to be maintained around 20%. The inductor value was calculated to be around 1.6mH. The capacitor value was obtained to be around 1000μF. A RCD snubber circuit is used to nullify the transients and achieve soft switching.

The input voltage, output voltage and the input current of the converter are sensed and fed to a MSP430G2x series microcontroller. These signals are then processed and the appropriate firing pulses for the Gate is given via a Gate Driver IC (UCC27322). Gate driver IC is used to achieve the required voltage level for driving the switch without loading the microcontroller. Operational amplifier LM358 is preferred over other op-amps in this subsystem as this IC does not require dual power supplies provided all the signal levels are positive. Regulated supply of +12V for powering this subsystem is derived from the PV panels using the Switching Voltage Regulator(TI -P/N TL2575).

B. Power Flow Management system Circuitry

The PMS circuitry is completely powered by the inverter battery. 10V supply for powering the op-amps is derived using adjustable voltage regulator (TI-P/N LM317).The ripples produced at the output of all voltage regulators are filtered out by capacitors. The PMS is implemented with the help of two relay switches, one to connect/disconnect the battery and the other relay to connect/disconnect the mains from the inverter. The relays are triggered by the microcontroller via a driver IC (TI -P/N L293DE) which is designed to drive inductive loads such as relays and solenoids. The dual supply required for the current sensor and op-amps is obtained using Switched Capacitor Voltage Converter IC (TI-P/N LMC7660) along with capacitor charge pumps. The schematic of the PMS is shown in Fig. 5.

Current sensors are used for measuring the current through the battery and from the PV panels. Since the current flowing through the battery is bidirectional, a negative voltage will be obtained at the output of the sensor during discharge. Since a microcontroller can process only positive voltage levels, a level shifter circuit that shifts the signal level by +1.5V is used. This is constructed using TL084 and a 1.5V linear regulator (TI-P/N TLV1117-15). The output of this sensor is passed to a RC filter to filter out the variations in battery current. The battery voltage is measured using an op-amp(TI-P/N TL084). The low input bias and offset currents which are necessary for the precise measurement of signal levels make this suitable for this subsystem. The output signals

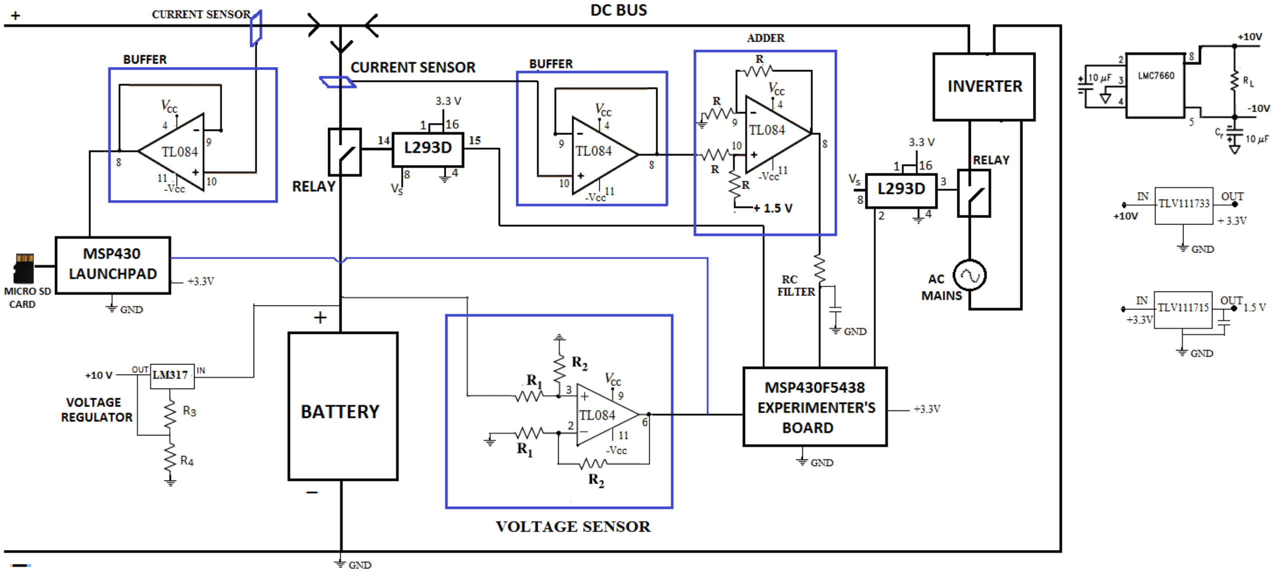

Fig. 5: Power Flow Management System Schematic

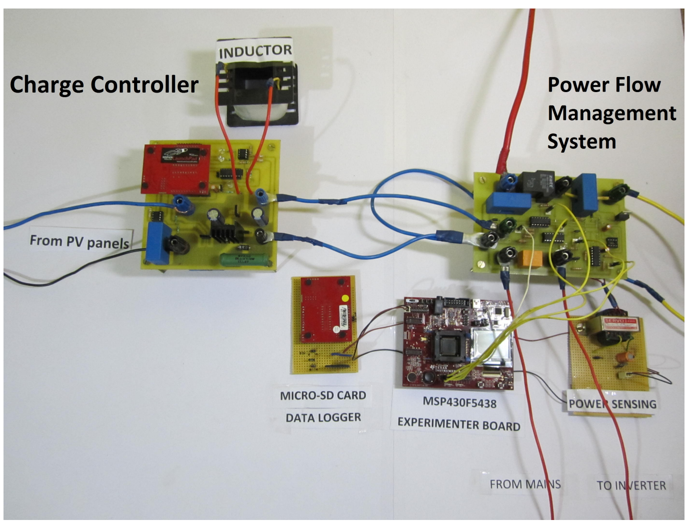

Fig. 6: System Setup

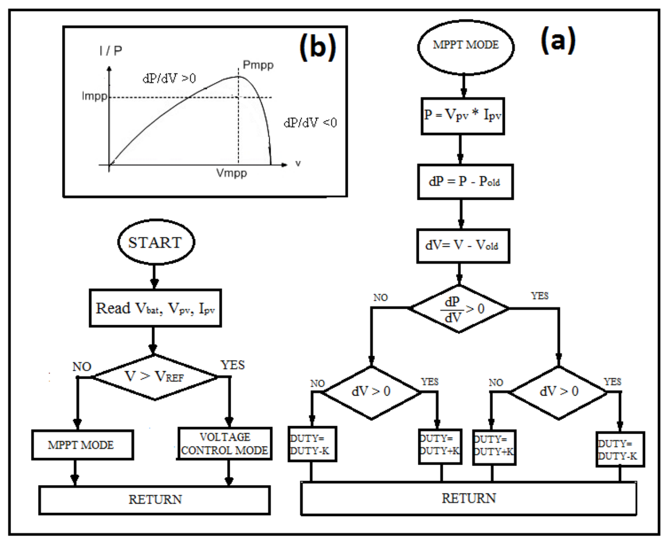

Fig. 7: a) Charge Controller Flow Chart b) Voltage versus Power curve of a PV panel

were then conditioned and fed to the microcontroller.

The MSPEXPF5438 Experimenter board is used as the main controller in this subsystem. This board features a graphic LCD display which is used to provide a user interface and also to display information like SoC, PV power etc. The portable energy monitoring device stores information like power and energy delivered by the PV panels in Micro-SD card. This uses a MSP430 Launchpad which contains a MSP430G2553 microcontroller. The complete hardware setup is shown in Fig. 6.

V. Software Implementation

The software codes for this project were written and debugged using Code Composer Studio which interfaces the microcontroller through the JTAG interface. The charge controller and PMS are implemented using appropriately formulated algorithms. The PMS interfaces a LCD display to implement a menu driven application for visual realization of the system working.

The charge controller operates in two modes - MPPT or Voltage Control Mode. When a predefined voltage reference of the battery is reached, Voltage Control Mode is implemented by reducing the duty cycle of the PWM pulses. The MPPT mode is executed using P&O algorithm by sensing the input voltage and current values and providing pulses of appropriate duty cycle as per the flow chart shown in Fig. 7 a.

The P&O is a hill climbing algorithm according to

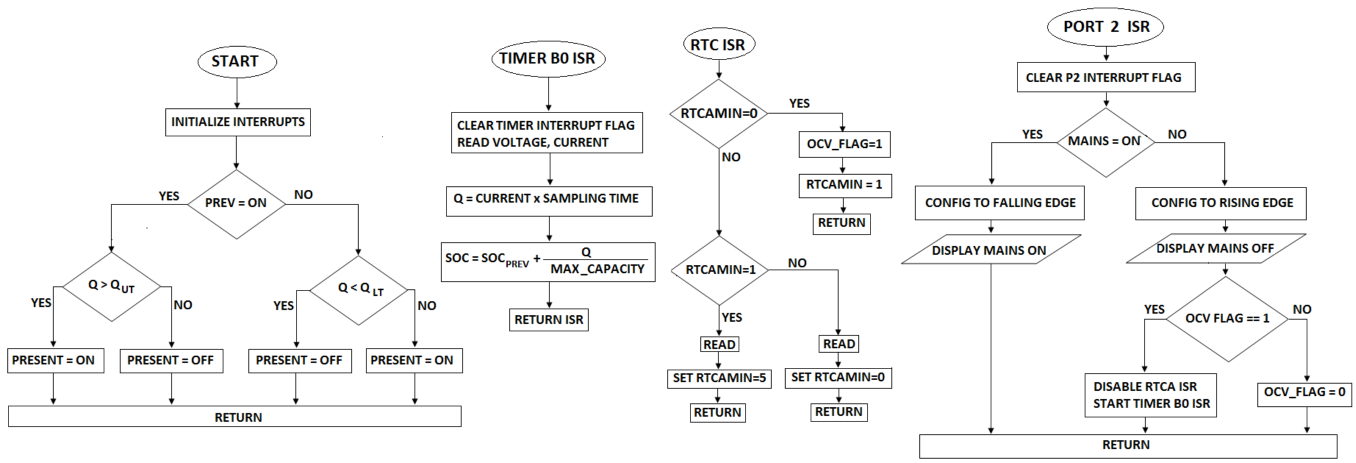

Fig. 8: Power Flow Management System Flow Chart

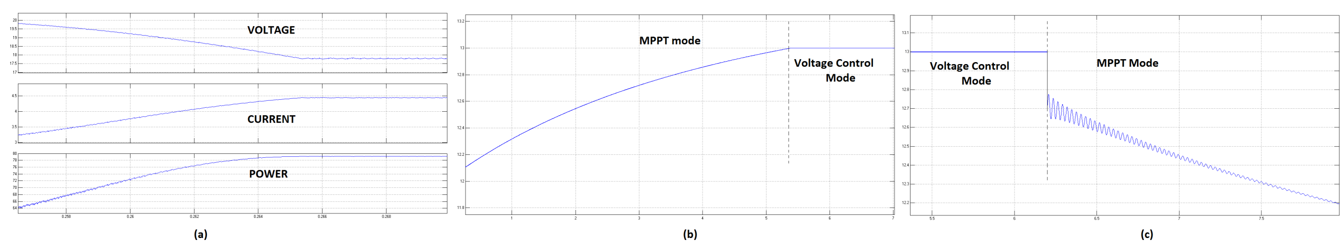

Fig. 9: Simulations response of the Charge controller a)Tracking of MPP b)shifting from MPPT to VOC mode c)Shifting from VOC to MPPT mode

which the controller perturbs the operating point and observes the change in power and voltage. Based on these values, further adjustments are made such that it reaches the maximum power point. As shown in Fig. 7b, the right of the P_{mpp} point has a negative slope (dP/dV$<$0) and has a positive slope (dP/dV$>$ 0) to the left. The point is perturbed and the power is observed and if dP/dV$>$0, the the operating point is moved towards the right whereas if dP/dV$<$0, the operating point is moved towards the left. Since there is always a small perturbation made in each cycle, the operating point of the PV panel oscillates around the maximum power point[9].

The PMS is implemented as shown in the flowcharts in Fig. 8. The program is mostly driven by interrupts and hence Interrupts Service Routines are used. The main program incorporates the power flow control strategy. SoC of the battery is calculated by sampling the current at periodic intervals set using TimerB0 interrupt.

The RTC-A module provides an interval alarm that sources real-time clock interrupt. This is configured to cause an alarm after one and five minutes by changing RTCAMIN register during which the voltage of the battery is measured. These measurements are used to calculate the OCV and hence recalilbrate the battery SoC. The OCVFLAG indicates the execution of recalibration process. If an external hardware interrupt is triggered, it indicates power failure during re-calibration process and the battery is reconnected to inverter restoring its usual operation. This trigger invokes the PORT2 ISR which re-initializes the coulomb counting process and abruptly stops the recalibration process. The Timer B0 and RTCA are software interrupts while PORT2-ISR is an external hardware Interrupt.

VI. Results

The charge controller was simulated in MATLAB-Simulink as shown in Fig. 9. Two PV panels of V_{oc}=22V, I_{sc}=4.7A and P_{max}=80W were connected in series for testing the controller. The experimental verification of MPPT mode is shown in Fig. 10. The initial duty cycle is fixed at 50% which lies to the right of the maximum power point (MPP) in the P-V curve. Thus the voltage decreases, current and power output increase to move towards the MPP. All the three parameters settle around the maximum power point thus verifying the working of P&O algorithm. While the MPPT tracker extracted 107.6W, directly coupling the panels to the battery gave only 50.4W.

The response of the controller in shifting from MPPT to VOC mode and vice-versa is shown in Fig. 11 and Fig. 12 respectively. The shift from MPPT to VOC mode was obtained by suddenly decreasing the load in a

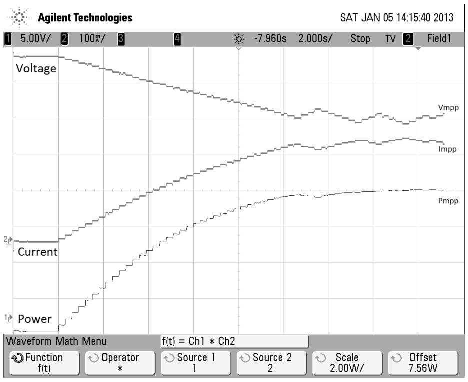

Fig. 10: Tracking of MPPT(CH1: 5V/div, CH2: 0.5A/div, Time:5 sec/div)

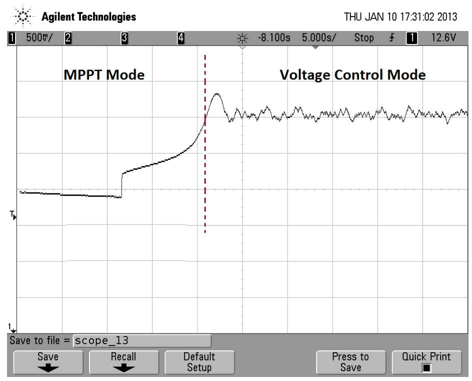

Fig. 11: Response of the controller for MPPT to VOC mode (CH1: 500mV/div, Time:2 sec/div)

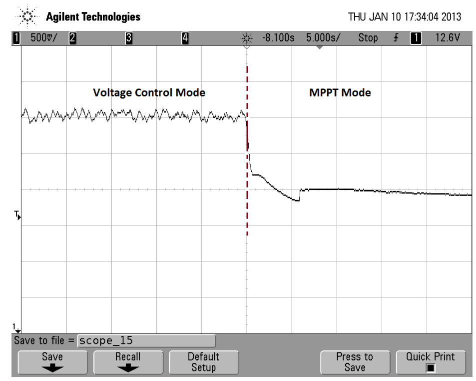

Fig. 12: Response of the controller for VOC to MPPT mode (CH1: 500mV/div, Time:2 sec/div)

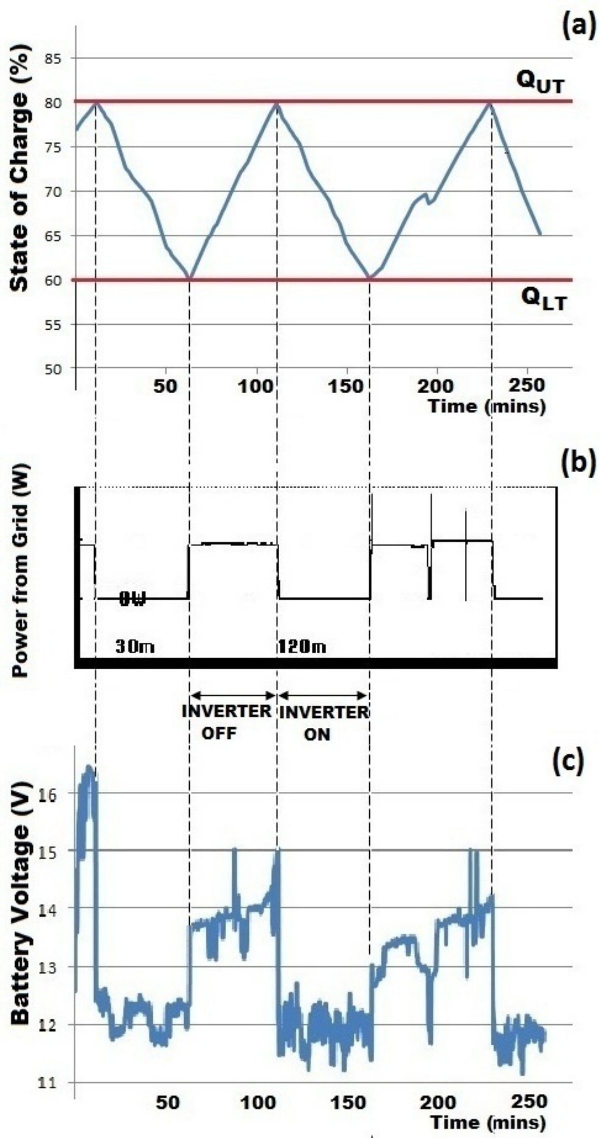

Fig. 13: a)Variation of SoC b) Power consumed from the Mains c) Variation of Battery voltage

sufficiently charged battery. The shift from VOC to MPPT was obtained by suddenly increasing the load.

The PMS was experimentally verified and the results for operation during the course of the day are shown for a fixed load. Fig. 13b shows the power consumed from the mains. The peaks indicate the charging of the battery from the mains and the small dips indicate the fluctuation of power in the mains. The power consumed is zero whenever the switch is turned OFF and the PV panels/battery supply the loads. Fig. 13a indicates the variation of SoC of the battery with time. The upper and lower thresholds are set to be 80% and 60% respectively. When the SoC goes above 80% (Q_{UT}), the mains is disconnected and the load demand is met by the battery and PV panels. This state is maintained until the battery SoC decreases to 60% (Q_{LT}) below which the mains is reconnected. The mains is disconnected again only when the SoC reaches 80% and this cycle is repeated. The battery voltage varies and has different values for the same SoC thus proving to be an ineffective parameter to indicate the amount of electrical energy stored in the battery and hence cannot be used to implement the control strategy.

Table 1 shows the tabulation of SoC obtained from Coulometric and Open Circuit Voltage prediction method. It can be seen that the OCV prediction method is accurate and can be used. Fig. 14a depicts the recalibration process using OCV prediction method. The battery is given a 5 minute rest period by disconnecting

TABLE I: Comparison of SoC determination methods for a 28Ah battery when discharged at 2A rate.

Actual SoC%	OCV prediction Method		Coulometric Method	
	SoC %	Error %	SoC %	Error %
52.34	51.30	2.00	51.03	2.51
45.31	45.64	0.74	46.00	1.52
35.94	35.14	2.21	34.38	4.34
30.47	30.04	1.40	29.69	2.55
34.38	34.73	1.03	34.86	1.42

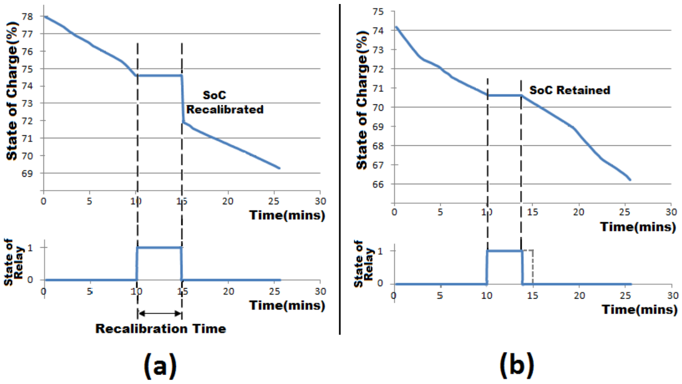

Fig. 14: a)SoC Recalibration process b) Interruption of power supply during the recalibration process

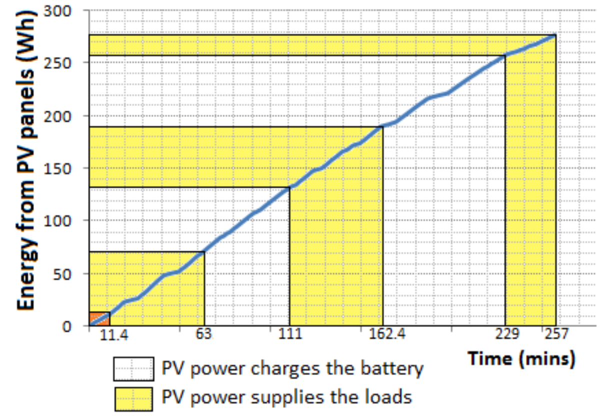

Fig. 15: Energy extracted from PV panels

it from the sytem. The OCV is predicted and SoC is calibrated from this value. Any power failure during this process is sensed and the recalibration is stopped instantaneously and battery is reconnected to the system to supply the loads as shown in Fig. 14b. The previous SoC value is retained.

Table 2 shows the energy extracted from the PV panels at different intervals. While commercial chargers stop extracting solar power once the battery is sufficiently charged(t =11.4 min), this system continues to extract solar power due to the implemented power flow control strategy. The total solar energy extracted is around 266Wh more than the commercial chargers (t=11.4 to 257 min).Thus for a fixed load of 135W, the PV panels (max power:160W) provide 48.1% energy savings when there is no power interruption. The energy extracted from the PV panels is shown in Fig. 15. The working of the project is demonstrated as a video[10].

TABLE II: Utilization of Solar energy

Time(minutes)	Inverter	Solar energy extracted(Wh)	Solar power supplied to
t = 11.4 to 63.0	ON	59.51	Loads
t = 63.0 to 111.0	OFF	61.41	Battery
t = 111.0 to 162.4	ON	58.52	Loads
t = 162.4 to 229.0	OFF	66.31	Battery
t = 229.0 to 257.0	ON	19.94	Loads

[1]Total energy supplied to loads = 137.65Wh
[2]Total energy supplied to battery = 127.27Wh
[3]Total Solar energy extracted = 265.92Wh

VII. Conclusion

The PV power has been effectively used for charging the battery and supplying the excess power to the loads using a Charge controller and a Power flow Management System. The energy consumption from the mains has been reduced and this has been experimentally proved. The system can be readily installed in homes without any modifications in inverter circuitry and requires no external power supply. The system is flexible and can be easily extended to meet the load demand by providing a charge controller for each additional PV panel set. Further optimizations in size and cost can be achieved by using cheaper current sensing solutions, smaller inductors, and cheaper displays instead of the Experimenter boards and fully optimized PCB designs.

This project is intended for use in developing countries where Grid connected PV systems are not encouraged. This work can be expanded by implementing a solar-wind hybrid system to move towards self sustaining and clean energy and thus is a future scope of this project.

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Appendix A
PCB designs

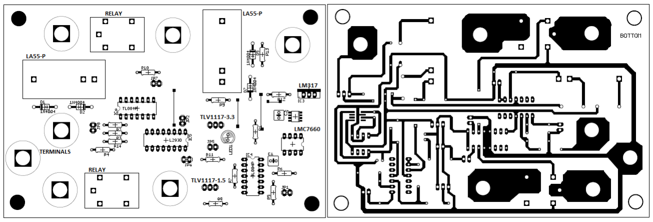

Fig. 16: Power Flow Management system PCB(scaled down to 25%)

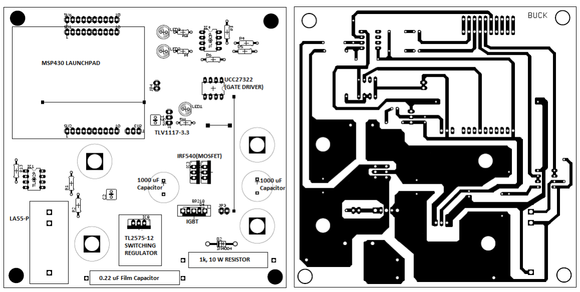

Fig. 17: Charge Controller PCB(scaled down to 25%)

Appendix B
Software code

1. Code for controller in PMS

```
 /* // Main function where Frequency
 of the clock, LCD, USB, RTC
 are initialised and configured */

void main()
{
        WDTCTL = WDTPW + WDTHOLD;
        P5DIR|=0x01;
        P5OUT|=0x01;
        P5DIR|=0x02;
        P5OUT|=0x02;
        freq_setup();
    halLcdInit();
    halLcdBackLightInit();
    halLcdSetBackLight(0xCF);
    halLcdSetContrast(100);
    halUsbInit();
    initi();
    adc_setup();
    P10DIR|=0x01;
    P10OUT |=0x01;
    P1DIR|=0x01;
    setupRTC();
    //Initialise Menu options
    menu_initi(count);
    power_interrupt();
    __bis_SR_register( GIE);
    while(1)
    {

    ADC12CTL0 |= ADC12SC;
        if(flag!=0)
        {
        if ( prev!=count)
        {
        menu_initi(count);
        prev=count;}
        }else
        {
                if(count==1&&flag0!=0)
                start();
                if(count==2&&flag1!=0)
                socpage();
                if(count==3&&flag2!=0)
                clockpage();
                if(count==4&&flag3!=0)
                batteryInit();
                if(count==5&&flag4!=0)
                powerPage();
        }
    }
}
/* //TIMERB Interrupt Service Routine
 for Coulomb counting process */
#pragma vector=TIMERB0_VECTOR
__interrupt void TIMERB0_ISR (void)
{
        TB0R=0x00;
        TB0CTL&=~TBIFG;
//Sampling Battery Current
while(!(ADC12IFG&BIT1));
    coulomb=ADC12MEM1_L;
    coulomb=coulomb|ADC12MEM1_H<<8;
//Sampling Battrery Voltage
while(!(ADC12IFG&BIT0));
    voltage=ADC12MEM0_L;
    voltage=voltage| ADC12MEM0_H<<8;
    coulomb-=1849;
    if(coulomb<0)
     {
        dischargeFlag=1;
        chargeFlag=0;
     }
    else
     {
    chargeFlag=1;
    dischargeFlag=0;
      }
//Coulomb counting
soc+=(double)coulomb*0.0803222;
if(soc>633600)
        {
    P5OUT|=0x02;      //Relay off
        prev_state=1;     //Relay off
        }
//Switching Strategy
 else if(soc<475200)
        {
        P5OUT&=~0x02;      //Relay on
        prev_state=0;      //Relay on
        }
 else if(prev_state==0)//Relay on
    P5OUT&=~0x02;
 else if(prev_state==1) //Relay off
        P5OUT|=0x02;
        coulomb=mod(coulomb);
    current=(double)coulomb*0.0803222;
    conv(current*10);
        if(currentFlag==0)
        {
        //Display Current
        }
     P10OUT|=0x01;
     P1OUT^=0x01;
}
//Real Time Clock Alarm ISR to Initialize
//recalibration Process.

#pragma vector=RTC_VECTOR
__interrupt void handle_rtc_interrupt(void)
{
        switch(__even_in_range(RTCIV,8))
    {
    case 6:
```

```
    P1OUT^=0x01;
    socpage();
    break;
    }//switch
}
//*******************************************
//Function to implement 1 minute and 5 minute
///SoC recalibration process
//********************************************
void socpage()
{
//Initiating the Recalibration process
if(RTCAMIN==(BIT7|0x31))
{int i;
        OCV_FLAG=1;
        TB0CTL&=~TBIE;
       TB0CCTL0&=~CCIE;
        for(i=13;i<=16;i++)
        {
      _delay_cycles(20000000);
        }

        P10OUT|=0x01;
        P5OUT&=~0x01;
        adc_value=0;
       MENU_FLAG=0;
       conv(soc/79.2);
       RTCAHOUR=BIT7;
        RTCAMIN=BIT7;
        RTCAHOUR|=0x09;
        RTCAMIN|= 0x32;
}
//Sampling Voltage at first minute
else if(RTCAMIN==(BIT7|0x32))
{
   ADC12CTL0 |= ADC12SC;
  for(i=0;i<10;i++)
  {
        while(!(ADC12IFG&BIT0));
      counter=ADC12MEM0_L;
      counter=counter|ADC12MEM0_H<<8;
      adc_value+=counter;
  }
        adc_value=adc_value/10;
        adc_value=adc_value*0.4520;
        adc_1min=adc_value;
//Display Voltage at First minute
        adc_value=0;
        min1_flag=1;
        RTCAHOUR=BIT7;
        RTCAMIN=BIT7;
        RTCAHOUR|=0x09;
        RTCAMIN|= 0x33;
}
//Sampling voltage at fifth minute
else if(RTCAMIN==(BIT7|0x33))
{
  for(i=0;i<10;i++)
  {
        while(!(ADC12IFG&BIT0));
   counter=ADC12MEM0_L;
   counter=counter|ADC12MEM0_H<<8;
         adc_value+=counter;
  }
       halLcdActive();
       halLcdBackLightInit();
       halLcdSetBackLight(0xCF);
       halLcdSetContrast(100);
       halLcdClearScreen();
        adc_value=adc_value/10;
        adc_value=adc_value*0.4520;
        adc_2min=adc_value;
    //Display 5min Voltage
    slope=(adc_2min-adc_1min)/0.7;
        slope/=100;
        voc=(1.64*slope)+(adc_1min/100);
        voc*=100;
        conv(voc);
        voc/=100;
 //Calculating the SoC
       adc_value=0;
        soc=50+78.125*(voc-12.20);
        soc*=100;
        conv(soc);
 //Display Recalibrated SoC
 //Reconfiguring the Recalibration timing
        RTCAHOUR=BIT7;
        RTCAMIN=BIT7;
        RTCAHOUR|=0x09;
        RTCAMIN|= 0x31;
}
 RTCCTL01&=~RTCAIFG;
 flag0=flag1=flag2=flag3=flag4=0;
}
```

2. Code for controller in Charge Controller

```
#include "msp430g2553.h"
void main(void)
{
        unsigned long int
i,vold,vnew,pold,pnew,voc=0;
        int flag=0,flag2=0,j;
         P1DIR&=~0x38;
        TACTL = TASSEL_2 + MC_1;
        CCR0 = 100;
        CCTL1 = OUTMOD_7;
        CCR1=50;
        _delay_cycles(800000);
        while(1)
        {
        //TAKING ADC VALUE OF INPUT CURRENT
        //input voltage and output voltage
        i=ADC10MEM;
        while ((ADC10CTL1 & ADC10BUSY) == 0x01);
        vnew=ADC10MEM;
                while ((ADC10CTL1 & ADC10BUSY) == 0x01);
                voc=ADC10MEM;
                pnew=vnew*i;
           if(voc>474)          //cutoff: 14V
                        flag2=1;
       if(flag2==0) //MPPT MODE
           {
         if (flag==0)
             {
                 pold=pnew;
                 vold=vnew;
                 flag=1;
             }
     else
     {
          if(pnew>pold)
          {
        if(vnew>vold)
                        CCR1=CCR1-1;
                else if(vnew<vold)
                        CCR1=CCR1+1;
            }
                else if(pnew<pold)
                {
                  if(vnew>vold)
                        CCR1=CCR1+1;
                        else if(vnew<vold)
                        CCR1=CCR1-1;
                }
                vold=vnew;
                pold=pnew;
         _delay_cycles(500000);
                }
        } //ENDIF MPPT

        else if (flag2==1)//VOC MODE
        {
```

TABLE III: **APPENDIX C - Bill of Materials**

S.No	Component/IC	Manfacturer	Cost per Component($)	Quantity	Total cost($)	TI supplied Purchased
1	UCC27322	TI	1.1	1	1.1	TI supplied
2	LMC7660	TI	0.35	1	0.35	TI supplied
3	L293DNE	TI	2.2	1	2.2	TI supplied
4	TL084IN	TI	0.24	2	0.48	TI supplied
5	LM358PE3	TI	0.14	2	0.28	TI supplied
6	TLV111733DCY	TI	0.32	4	1.28	TI supplied
7	TLV111715DCY	TI	0.32	1	0.32	TI supplied
8	LM317T/NOPB	TI	0.61	1	0.61	TI supplied
9	TL2575-12IN	TI	1.1	1	1.1	TI supplied
10	MSP430G2 Launchpad	TI	4.3	2	8.6	TI supplied
11	MSP430F5438 Experimenter Board	TI	149	1	149	TI supplied
12	IRGPH150F	International Rectfiers	1.5	1	1.5	Purchased
13	IRF540N	International Rectfiers	0.37	1	0.37	Purchased
14	LA55P	LEM	13.63	3	40.89	Purchased
15	Generic Components	-	-	-	10	Purchased

```
        if(voc>470)
                  //maintain at 14V
               CCR1=CCR1-1;
        else if((voc<470)&&(voc>450))
               CCR1=CCR1+1;
        else if(voc<457)
          //move to mppt below 13.5V
               flag2=0;
        }
        _delay_cycles(200000);
        }       //end voc
} //end while
} //end main
```

Appendix C
Bill of Materials

The bill of materials is presented in Table 3. Table 4 gives the summary of the project.

TABLE IV: Summary

Total Cost of the Project	$ 210.36
TI Analog ICs used	9
Other TI ICs used	2