# Prediction based Battery Power Management using Solar Energy

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***Abstract*—— In this paper a prediction based battery charging technique is employed which enables intelligent or smart battery charging decisions. Specifically, the system will use Mains (Main-Grid) only when Solar charging is insufficient. The system will decide when to preserve battery and use Mains as direct supply to loads. These decisions are made to utilize more solar energy and less Mains electricity while maintaining high reliability. Smart Solar Charge Controller which is part of solar power system is designed such that the solar battery gets recharged quickly and does not get over discharged thereby ensuring the prolonged lifespan of the solar battery. Once it reaches fully charged condition, a logic system in the charger will keep the battery on trickle charge. The charge controller will have smart battery management system in built. This paper is further implemented such that whenever there is excess solar energy after the battery is sufficiently charged, that excess energy is supplied to loads through the grid thus reducing the energy consumption from the grid. Maximum power point tracking battery charger is proposed for extracting maximum power from a Photovoltaic panel to charge the battery. The system is composed of a microcontroller, solar panel, a buck type DC-DC converter, a resistive load, and lead acid battery.**

***Keywords—Photovoltaic (PV), maximum power point tracking(MPPT).***

## I. INTRODUCTION

Energy which comes from natural resources such as sunlight, wind, rain, geothermal heat etc. is called renewable energy. Renewable energy resources are inexhaustible, clean as compared with conventional resources. About 16% of global final energy consumption comes from renewable resources. Solar Photovoltaic energy has many advantages like clean-green energy, free and abundant, environment friendly, low operation and maintenance cost, etc. and hence the demand is increased.Many types of Photovoltaic power conversion systems have been developed including the grid-connected system for reducing the power from the utility and the stand-alone system for providing the load power without the utility. In case of stand-alone system is usage, batteries are required for energy storage. Electricity generations of solar panels are strongly related with solar radiation intensity. However the intensity is not stable. Therefore, charge efficiency is a very important topic in solar systems. Charge controllers are designed to improve charge efficiency and safety. The primary function of a charge controller is to protect the battery from overcharge and over discharge in a stand-alone photovoltaic system.

In developing countries like India, the demand for power is increasing and there are scheduled power outages. Photovoltaic being intermittent in nature, energy storing devices such as batteries are integrated into the system to meet the dynamic power demands. A photovoltaic system implemented in houses involves two power sources (photovoltaic 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 photovoltaic systems.

The main motivation of the paper 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.

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 an existing home inverter system. 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.

When AC main fails, inverter section will provide uninterrupted AC power supply which should be maintained by the storage batteries. These storage batteries will be charged efficiently by the solar source when sunlight is available regardless of the AC line status. While, in dark night or cloudy weather AC grid source will charge the batteries. We are using PV array of medium capability in this prototype but it is restricted to charge the battery and being miniature amount, harvested AC will not be reflected to Grid which is left open for future.

## II. TECHNICAL BACKGROUND

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 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. Battery voltage is not an accurate indication of the amount of electrical energy stored inside the battery. 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. 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-discharges of the battery which is not accounted. 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. So a combination of both OCV and Coulomb counting is required to cover the weakness of both techniques and deliver an accurate monitoring system. Thus the proposed system uses both techniques to estimate the accurate SoC. The SoC of the battery during run time is calculated using Coulomb counting and it is re-calibrated periodically using OCV method.

Though many novel ideas and hi-techniques are being developed, there is still lack of appropriate techniques for proper utilization of multiple charging sources. Majority of the charging techniques developed till now basically deals with maximizing power utilization of a single source. However these techniques do not enable smart charging decisions to ensure efficient use of multiple charging sources (e.g. Main-Grid and Solar). For instance, these controllers do not decide when it is appropriate to charge battery using Mains (Main-Grid) in addition to Solar. Such decision abilities could be desirable for places affected by load-shedding. Due to unorganized charging, batteries in such places are either insufficiently or unnecessarily charged. For example, if the batteries are charged by PV panels alone, it may not be sufficient during high load shedding periods. This will interrupt continuous power supply. On the other hand, if the batteries are also charged by main line without any smart decision, then they may be unnecessarily charged. This will simply mean unnecessary loss during the conversion process.

## 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*

A solar charge controller or regulator is a small box consisting of solid state circuits PCB which is placed between a solar panel and a battery. The main function is to regulate the amount of charge coming from the panel that flows into the battery bank in order to avoid the batteries being overcharged.

Solar charge controller has three basic functions:

1. To limit the voltage from the solar panel and regulate the same so as not to overcharge the battery.

2. Do not allow the battery to get into deep discharge mode while dc loads are used.

3. To allow different dc loads to be used and supply appropriate voltage.

Solar Charge Controller act as the central control unit regulating the overall energy flow in Solar Home System and photovoltaic hybrid 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.

$$SoC = SoC_{init} + \int idt \qquad (1)$$

*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.1

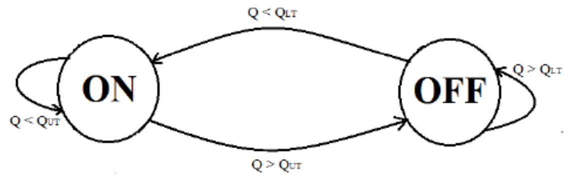



Fig.1 State diagram of the Control strategy

A two level threshold limit of SoC is used for the control strategy. The upper threshold charge (QUT) 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 QLT corresponds to a minimum SoC that the battery has to maintain to prevent deep discharge. Below QLT, 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 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. BLOCK DIAGRAM

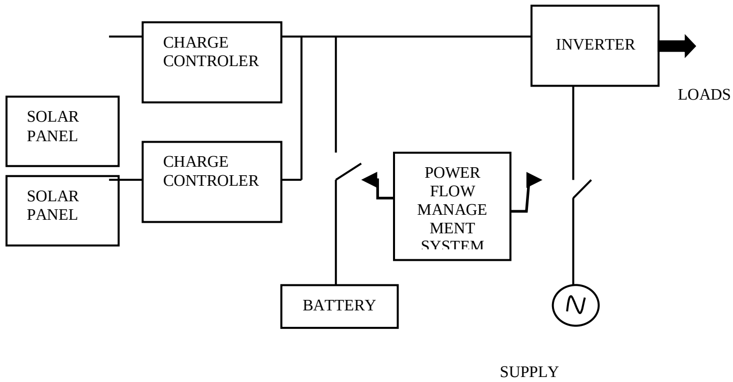
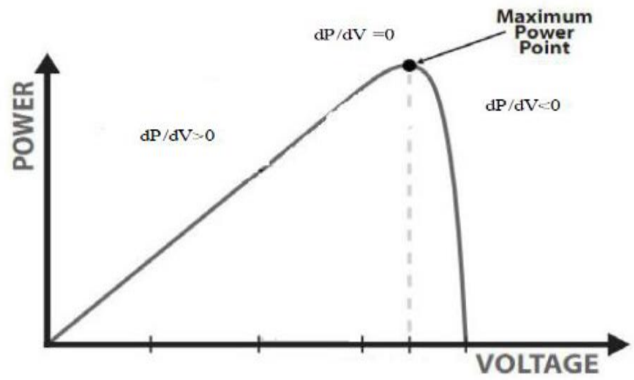



Fig.2 Block diagram

A Solar cell or photovoltaic cell is a device that converts light directly into electricity by the photovoltaic effect. Photovoltaic cells combined together to make solar panels, solar modules, or photovoltaic arrays.




Fig,3 Power Voltage characteristics of PV array

The solar panel used here is meant to charge a 12V battery and the wattage can range from 200W-500W. Solar cells are usually made from silicon, the same material that is used for making transistors and integrated circuits. In order to generate electric current the silicon is doped or treated so that when light strikes it electrons are released. Types of Solar panels or PV modules: crystalline (monocrystalline and polycrystalline) and amorphous. Crystalline solar cells are wired in series to produce solar panels. To charge a 12V battery 36 cells are required to produce an open circuit voltage of about 20Volts as each cell produces a voltage of between 0.5V-0.6V. Monocrystalline are more efficient than polycrystalline but also the most expensive. Amorphous or Thin film-technology is most often seen in small solar panel, such as in calculators or garden lamps. The efficiency of amorphous solar panel is not as high as crystalline solar cells and it is less expensive.

*Commonly used charge controllers are namely:*

1. Series charge regulators

2. Shunt charge regulators

3. DC-DC converter

Various types of charge controllers are available. Analog type charge controllers include operational amplifiers which indicate the battery status by glowing the LED. The status of battery can be known by LED. ON/OFF charge controllers simply make ON and OFF the controlling element like MOSFET so that either full or no current will be passed to the battery.

PWM (pulse-width modulated) charge controllers which charge the battery with constant voltage or constant current are also being used. They have a power device like MOSFET which is made ON and OFF. The efficiency of PWM charge controllers is higher than Analog and simple ON/OFF charge controllers. PWM have ability to recover battery capacity, to increase charge acceptance of the battery. The PWM based charge controllers extends the life of the battery and saves the cost by reducing size.

The MPPT types are newly introduced and are latest trend in market. They are more costly and better suited to large systems, when the investment in an expensive MPPT regulator gives quick returns. The MPPT charge controllers charges the battery at full power by maintaining efficiency of 90% to 93%. Among all discussed charge controllers in this report, the MPPTs provide excellent efficiency however they are costly.

The proposed solar charging application require a deep cycle battery. Deep cycle batteries have larger plates and different chemistry to avoid the corrosive effect of frequently using the full capacity. The solar energy is converted into electrical energy and stored in a lead-acid battery. The ampere-hour is the rated capacity of the battery. There are a few types of lead acid deep cycle batteries:

*Flooded:* Flooded batteries have the advantage of being significantly less expensive, but they require adequate ventilation, maintenance, and also have the potential liability of tipping or spilling.

*Sealed gelled:* gel batteries need to be recharged in a specific way that is not optimal for solar.

*Sealed AGM:* AGM batteries are typically lighter and less expensive per amp-hour compared to gel.

If lead acid batteries are maintained properly, they will function at 80-90% efficiency. To extend the life of the battery and maintain efficiency it is important to maintain a full charge under most condition. The advent of pulse width modulated controller made possible the efficient three stages charging or trickle charging from a PV array. This system charges battery with high frequency electrical pulses and by varying these pulses the amperage being delivered can be continuously changed. When the batteries are discharged the PWM senses this from the battery bank voltage and stays on to deliver full current and this stage is called bulk stage of charging. The next stage of charging is absorption and occurs as the batteries approach a full state of charge (SOC). The controller holds battery bank voltage constant for a period of time and the ―off time of the pulses is increased to gradually reduce current as the bank is topped off. The float charging stage occurs when the batteries are full and is also called the trickle charging.

## V. 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 (TIP/NTLV111733).

### *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 relation:

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

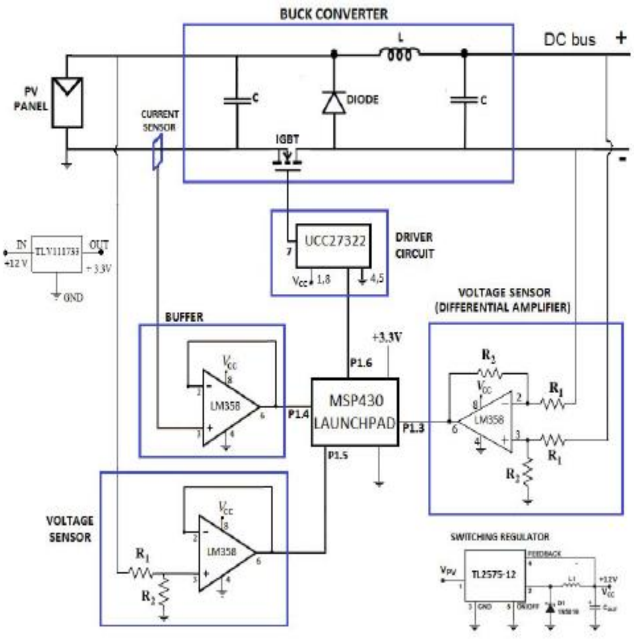



Fig.4 Charge controller schematic.

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 are 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/NTL2575).

### *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 (TIP/NLM317).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/NLMC7660) along with capacitor charge pumps. The schematic of the PMS is shown in Fig.

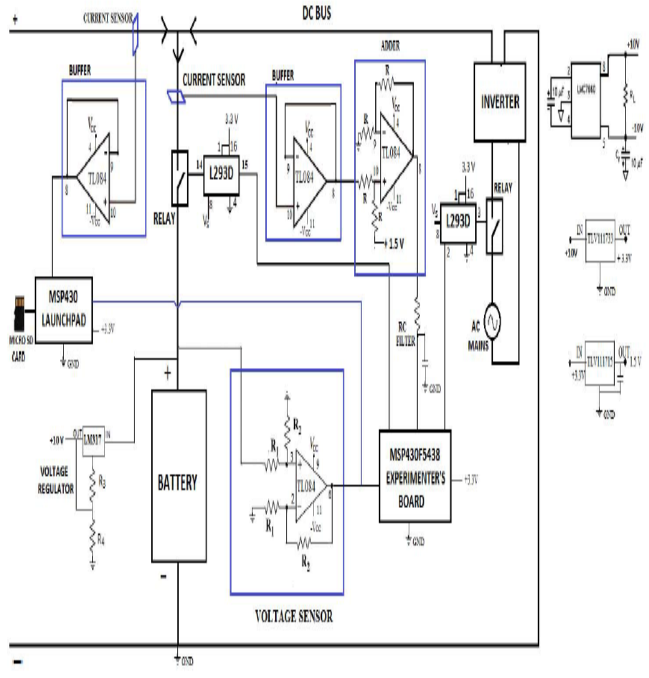



Fig 5. Power flow management system schematic

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 (TIP/ 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 (TIP/ NTL084). 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 were then conditioned and fed to the microcontroller.

Table I
OPERATIONS ACCORDING TO BATTERY CONDITIONS

| **Battery condition** | **Operations** |
|---|---|
| Insufficient | Mains added as charging source<br>Preserve Battery<br>Mains as direct supply source to Loads |
| Sufficient | Preserve Battery<br>Mains as direct supply source to Loads |
| Excess | Battery as direct supply source to Loads<br>Mains not used |

## VI. CONCLUSION

This paper has presented a prediction based technique for battery charging in solar home systems. The technique enables intelligent battery charging decisions based on calculated prediction of battery’s future state to utilize more solar energy and less Mains electricity while maintaining high reliability. The system has superior performance as observed from the hardware results and also the implementation can be easily done in the pre existing systems with simple design modifications Therefore, the designed technique is flexible, effective and easy to implement. Low cost high performance microcontroller based solar charge controller has been proposed. The proposed system used solar PV module as the input and DC load as the output. The proposed system has an upgrade option to control normal ups, when connected with the solar charger will convert to solar inverter/ups with solar charge as priority.

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. 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.

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