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Designing and Fault Analysis of a Charge Controller for PV System

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Abstract - This aim of this paper is to study the performance of a charge controller in combination with a Solar Photovoltaic (PV) system for improving the charging and discharging of the battery. The solar charge controller will forestall the overcharging of the battery hence will be valuable for protracting of its life expectancy. It will likewise help in preventing the reverse flow of electricity from the batteries to the solar panels in absence of solar power. Sun oriented charge controller will be valuable in obstructing the invert current stream which in any case may cause discharging of the batteries in dark. The results obtained demonstrate the great performance of the charge controller also because the benefits of its use within the power quality improvement. Paper also analyses the various possible faults which may occur in PV system and uses Graphical User Interface to display their occurrence. It will help in rectifying the faults and hence will improve the stability of PV system.

Key Words: Controller, Fault Analysis, PV System, Battery Life, MATLAB, SIMULINK, MPPT

1. INTRODUCTION

India is a tropical country where the amount of sunlight is mostly available to meet up the demand of producing electricity. Solar energy is a perfect solution because it is completely clean in terms of pollution and health hazards. As it can replace expenditure over transmission lines, it's economical also. As there is a drastic hike in Day to Day crisis of energy whereas no other solution is left, without using the solar energy or turbine to get electricity. Again, we face power emergency as well as day by the expense of gas and other regular assets like fuel, diesel, oil and so on are ascending that is going past the accessibly of general individuals. Thereby such a system that can reduce the electricity crisis is desirable. Being a renewable source of energy, such a system enables to possess a more durable source of energy which may be employed by the longer-term generations to return without the burden of ever running day.

1.1 Degradation mechanism in Li-Ion Batteries

In the category of rechargeable batteries lithium-based batteries are most commonly used as they have the advantage in terms of specific energy and is therefore preferred in compact designs. For understanding the charging strategy to be used in power management for the effective performance of the battery, it is essential to have a knowledge about the capacity degradation mechanism of the same.

- The charging mode consists of two phases, constant current and constant voltage.
- The constant current phase is responsible for charging the battery to a level of 70 to 80 % and consumes 20 to 30 % of total charging time.
- At constant Voltage phase for 70 to 80 % of total time and only 20 to 30 % charge of total capacity accumulates.
- The constant voltage phase contributes little towards the capacity but accelerates the capacity degradation.
- The constant current phase should be done at low current ratings; 0.5 C is recommended.
- The discharge rates should be kept at a low level because the life-cycle depend proportionally on the discharge rates.

2. PROPOSED APPROACH

2.1 Architecture of Power Management Circuit

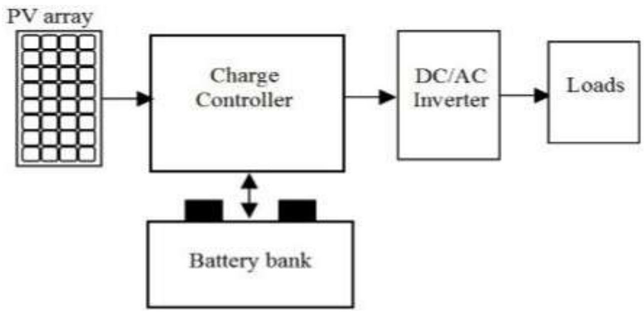

Fig – 1 : Architecture of PM Circuit

2.1.1 PV Module

It is used for solar power harvesting which is that the main source of energy for the sensor node. The output power from PV isn't stable and depends on the irradiance and temperature. The power output from Solar array variate according to different irradiance and temperature level. At the particular irradiance and temperature level, the P-V curve of the photovoltaic panel is non- linear and a maximum power point exists. Therefore, for max utilization of solar power, we require a maximum point tracker (MPPT).

2.1.2 Battery and Supercapacitor

Li-ion battery and Supercapacitors are used for electric storage. In which primary storage is referred to battery and supercapacitor act as secondary storage. This hybrid storage technique offers increased lifetime. Due to low leakage charge battery is used for holding the charge for a long time and is discharged only when solar energy is not available and supercapacitor storage is exhausted.

The role of supercapacitor changes in accordance with the mode of operation, when solar power is available it smoothens the energy flow to match the charging profile of the battery resulting in a constant DC Bus voltage. During unavailability of solar power, the supercapacitor gets dripped charged from the battery and supply at the time of peak power demand.

2.1.3 DC-DC Boost Converter

A Boost converter steps up the DC voltage and is required wherever source voltage is lower than the load voltage. This converter is used to realize the MPPT of the panel. The controller adjusts the duty cycle of the switch to control the input voltage V_{PV} for maximum power point. For effectively controlling the input voltage, equation suggest that V_{BUS} is kept constant.

2.1.4 Bi-Directional Converter

The DC-DC supercapacitor converter is a bidirectional converter, as shown. This converter is liable for controlling DC bus voltage during a narrow band by acting as a source or sink counting on the instantaneous power budget. Due to intermittent nature of solar energy, the energy mismatch between source and load is normal, which manifests as undesired conditions of under and over voltage on DC bus. Supercapacitor acts as a shock to the system and smoothens out these energy fluctuations.

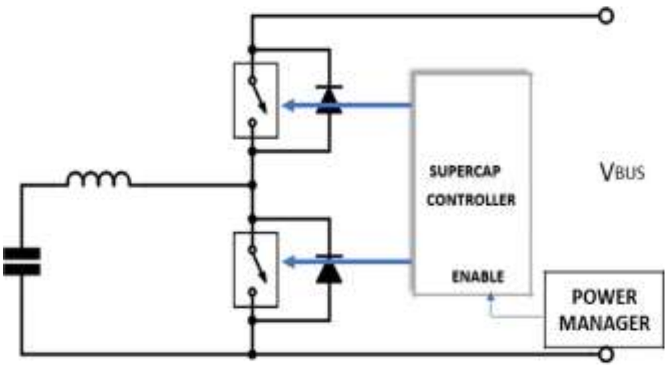

Fig – 2: Bi-Directional Converter

2.1.5 Supercapacitor Sizing

Supercapacitor is responsible for following functions:

- Peak demand supply in absence of Solar Power.
- Maintains constant DC Bus voltage

$$C = \frac{2 \times V_{load} \times I_{load} \times T_{peak}}{V_{sc}^{2}}$$

2.2 Estimation of Converter parameters

For Boost Converter

Inductor Selection

$$L = \frac{V_{IN} \times (V_{OUT} - V_{IN})}{\Delta I_L \times f_s \times V_{OUT}}$$

Where, V_{OUT} = desired output voltage

V_{IN} = typical input voltage

ΔI_L = estimated inductor ripple current

A good estimation for inductor ripple current is 20% to 40% of the output current.

ΔI_L = (0.2to0.4)× $I_{OUT(max)}$

$I_{OUT(max)}$ = Maximum Output Current

fs = Minimum switching frequency of the converter.

Output Capacitor Selection

$$C_{OUT(min)} = \frac{I_{OUT(MAX)} \times D}{f_s \times \Delta V_{OUT}}$$

Where, I_{OUT} = maximum output current of the application

ΔV_{OUT} = desired output voltage ripple

f_s = minimum switching frequency of the converter

D = duty cycle

$$D = \frac{I_L \times f_s \times L}{V_{IN(MIN)}}$$

3. SYSTEM MODELLING

3.1 PV Cell Model

A current source is connected in parallel to diode. The output of the present source is proportional to the incident photon flux this current is named photocurrent. During darkness, the photovoltaic cell isn't active and behave as a standard contact diode and this gets modeled as a diode within the equivalent circuit. It produces neither a current nor a voltage. This comes into action whenever a possible difference exists between the terminals of the photovoltaic cell and constitutes a current called Dark current. This diode determines the I-V characteristics of the photovoltaic cell.

Following are the parameters which are necessary for improved accurate modeling of PV cell: -

- Dependence of the diode saturation current (reverse) on temperature Is.

- Dependence of the photo current I_{ph} on temperature.
- Series resistance R_1, representing internal losses due to current flow.
- Shunt resistance R_2, in parallel with the diode, this corresponds to the leakage current.

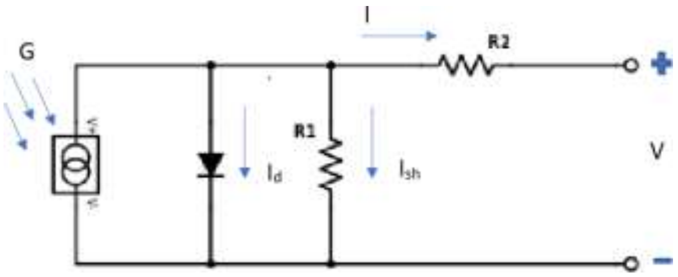

Fig – 3: Equivalent Circuit Of Solar Cell

3.2 Maximum Power Point Tracking Algorithm

Solar array have non-linear P-V characteristics for different values of irradiance and temperature. To track MPP in this system we need MPPT algorithm. Various methods are present in literature to understand MPPT, Every technique has their own advantages . Some of the famous techniques are listed below:

- Perturb and Observe (P and O)
- Incremental Conductance (IC)
- Fractional Open Circuit Voltage (FOCV)
- Fractional Open Circuit Current (FOCI)
- Neural Network

Among these techniques most commonly used is "P and O" and "Incremental Conductance". In this paper Perturb and Observation technique is employed for tracking MPP. This is based on hill climbing technique and is easy to implement and gives a good efficiency when irradiation is constant.

3.3 Algorithm for Power Management

This section contains the detailed Simulink model of power management algorithm which is predicated on six different states.

States of Power Management Algorithm when solar energy (PSOLAR) is available:

OFF State: - All the storages are discharged, all the converters are disabled.

Soft Start: - When P_{SOLAR} is larger than the power required by controller work.

Battery Charge: - This mode is enabled when V_{SC} reaches 1.9 Volts, this ensures that the system has enough energy to supply constant current for battery charging.

Overvoltage: - When V_{SC} reaches to a voltage greater than its maximum voltage limit this mode gets activated and requires MPPT to be disabled as P_{SOLAR} is greater than the load and battery charging requirement.

Disable Battery Charge: - When battery voltage reaches at floating value

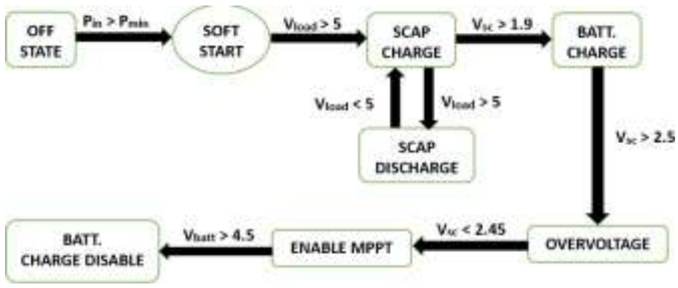

Fig – 4 Power Algorithm Flowchart

4. FAULT ANALYSIS

4.1 Various faults and their occurrence

The behavior of the circuit is studied under faulty conditions and a relationship between various voltage and current values in the sub systems is inferred from the data. These relationships are used for classifying faults

There are various types of faults occurring:

- Input Overvoltage Fault:

During operation, If the voltage crosses a prescribed value, the solar charge controller instantly registers an Input Over Voltage Fault. The fault automatically gets clear when the voltage falls to its prescribed value for 5-10 seconds.

- Battery Overvoltage Fault:

Battery Over Voltage Fault appears when the battery voltage exceeds the working limits and the solar charge controller stops charging for battery protection. The fault detection takes place when battery voltage rises above the nominal voltage plus:
4.5 V per 12 V (for example, above 49.5 V in a 36 V system) for 1 second.
The fault automatically gets clear when battery voltage falls to the nominal voltage plus 3.5 V per 12 V for 10 seconds.

- Battery Undervoltage Fault:

The Battery Under Voltage fault appears when the battery voltage falls to the nominal battery voltage.

- Output Overcurrent Fault:

Output Over Current Fault appears when the output current rises above the prescribed value.
The fault clears when output current falls below the operating limit for three seconds.

- Ground Fault:

Blowing of Ground fault protection (GFP) fuse results into this fault.

In this paper all the above faults are simulated for our designed Charge Controller and PV Systems along with the GUI Response for that particular fault.

4.2 Healthy System GUI

Following is the Graphical User Interface result when there is no fault.

If there is no fault, System can work at its maximum efficiency and Stability. Due to this GUI, user can also remain updated about the ongoing situation of the system. This will help the user to monitor the System remotely so that he can take adequate actions.

Fig – 5: GUI output for Healthy System

4.3 Fault Generation

Following are the possible reasons and the ways which can result into the generation of faults in the PV System (Charge Controller Sub System).

Table – 1: Fault Generation

Type of Fault	Reason of Occurrence
Input Overvoltage Fault	Due to malfunctioning of Boost Converter
Battery Overvoltage Fault	Charging using higher voltage/ Increase in Battery Internal resistance due to aging.
Battery Undervoltage Fault	Due to Short Circuiting of battery terminals.
Output Overcurrent Fault	Due to increase in load Demand
Ground Fault	Due to blowing of GFP Fuse

4.3.1 Battery Overvoltage Fault

Following is the Graphical User Interface after generating the Overvoltage fault for Battery.

This fault occurs whenever there is over voltaging of battery. Diagnosis of this fault is necessary because Over Voltage affects the Battery performance and Decreases battery life.

Fig – 6: GUI output for Battery Overvoltage Fault

4.3.2 Battery Undervoltage Fault

Following is the Graphical User Interface after generating the Under-Voltage fault for Battery.

This fault occurs whenever there is Under voltaging of battery. Diagnosis of this fault is necessary because Under Voltage effects the Battery performance and Decreases battery life.

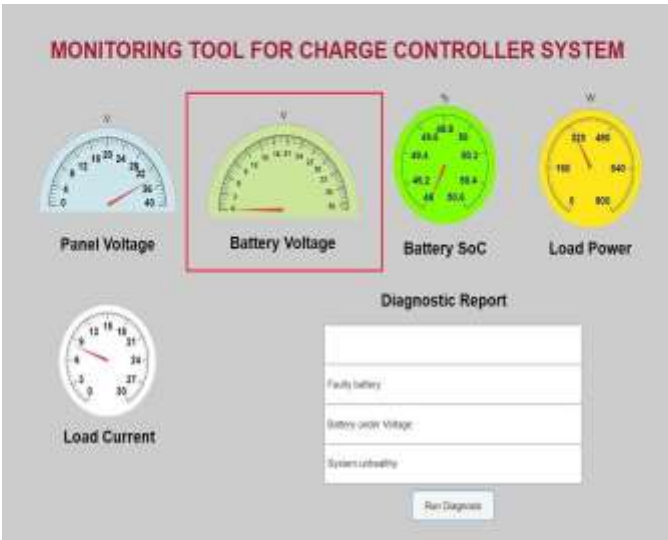

Fig – 7: GUI Output for Undervoltage Fault

4.3.3 Output Overcurrent Fault

This fault occurs whenever current drawing increases at output side. Over current output takes place due to variations in load. This fault can cause rapid discharging of battery and also effects its life.

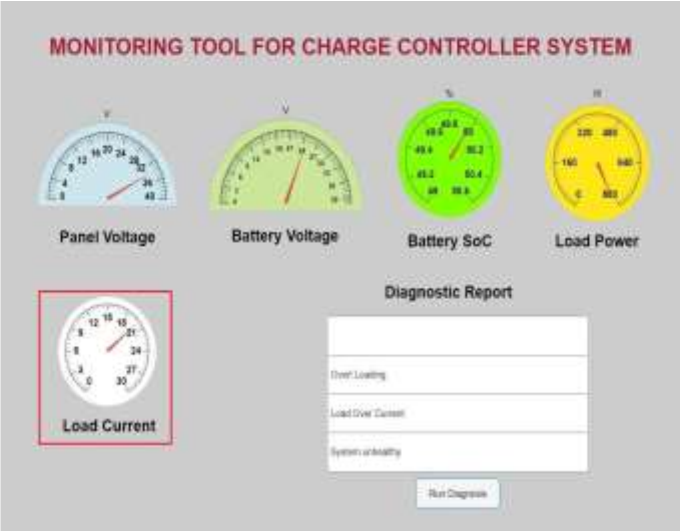

Fig – 8: GUI Output for Output Overcurrent Fault

5. SIMULATION RESULTS

5.1 PV Panel Input

Following graph shows the irradiation falling on solar panel and its temperature. As irradiation cannot be constant so here an arbitrary signal having maximum irradiation of 1000 W/m^2 is considered.

Here whole day scenario is scaled down in few seconds.

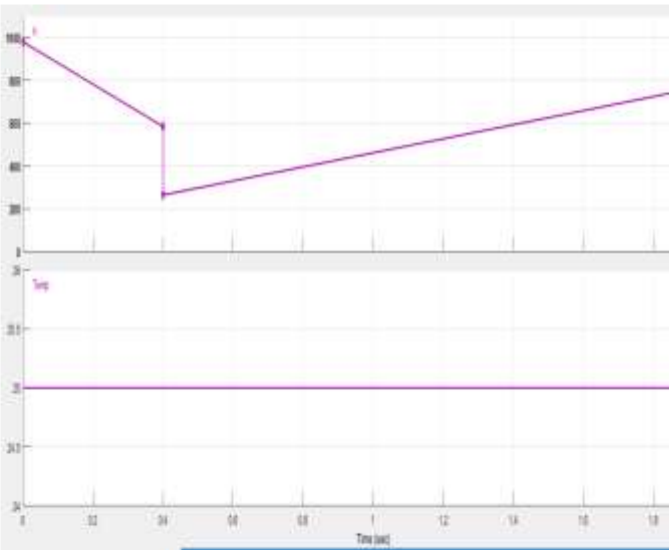

Fig – 9: PV Panel Input

5.2 Output Results – Battery and PV Panel Scope Characteristics

Battery scope consists of three plots i.e. Voltage, Current and State of Charge (SoC) plots.

From SoC plot we can infer that SoC of the battery is 50% initially. From the solar panel input we can see that initially irradiation level is more than sufficient to supply the load. Hence the charging of the battery takes place till there is the drop in irradiation level.

Once the irradiation level drops, discharging of the battery takes place and the load is partially supplied by PV Module and the Battery. Whenever irradiation drops to zero, complete load is driven by the battery. To fulfill the constant demand.

PV panel scope results shows that there is direct proportionality between current and illumination level. As irradiation level decreases, there is the decrease in the current. Hence the load supplied by the panel also decreases.

5.2.1 Battery Scope

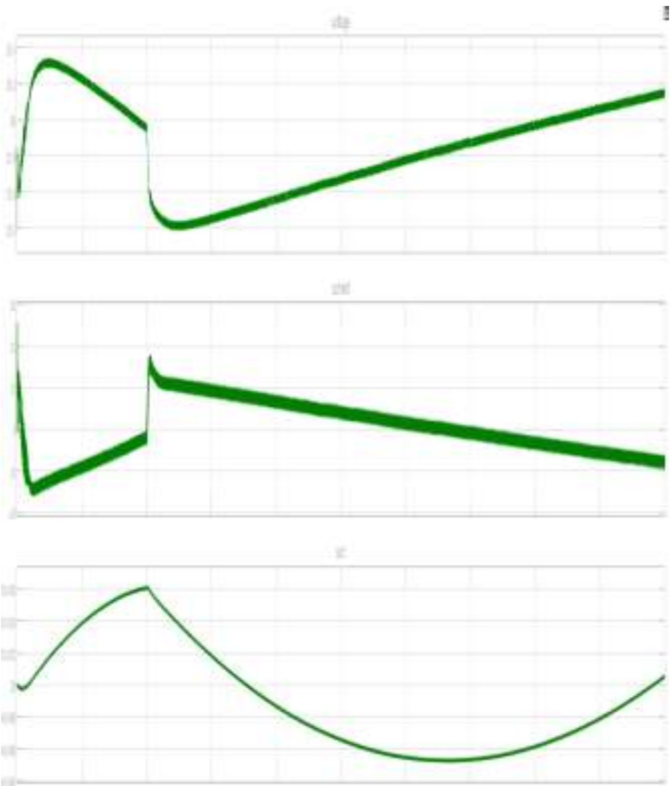

Fig – 10: Battery Performance Characteristics

5.2.2 PV Panel Scope

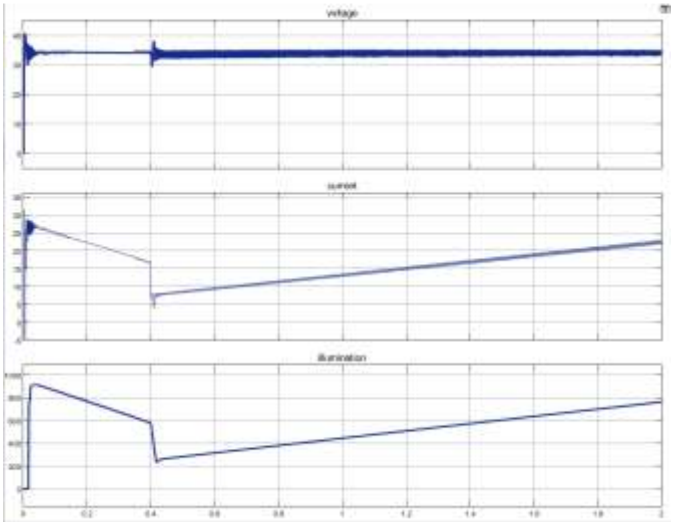

Fig - 11: PV Panel Characteristics

6. CONCLUSION

According to the irradiation data available and the required total demand, we found that whenever solar radiations are able to meet the required demand, whole load is being supplied by PV Module along with the charging of the battery.

This stored energy inside the battery can be utilized whenever sufficient solar power is not available to drive the load. There are situations when load fulfillment is partially done by PV Module and Battery depending on the amount of solar energy available.

We have also concluded that there are various faults occurring in the Charge Controller due to the malfunctioning of its various components along with the reasons responsible for the same. This work is performed to effectively manage load sharing between PV Module and the Battery so that better efficiency is obtained.

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BIOGRAPHY

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