Modeling of Battery Management for Standalone PV System

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Abstract. This work is focused on developing a model for a Battery management unit for a Solar PV based off grid standalone system and implementing the same using MATLAB tool. A secondary storage device in form a battery is essential to provide an energy backup in any autonomous system. In this work Lithium ion (Li Ion) battery has been considered for modeling as it offers good charge and discharge profile, high power density, occupies less space and less maintenance. It is essential to ensure secure function of such batteries by closely monitoring and control of their State of Charge (SOC). Determination of SOC ensures the remaining energy available in the battery which further helps in discharging the same based on system requirements. The major components of this work include representation of PV source, employing MPPT, regulating the DC output via boost converter, inverter and controlling the flow of energy between the source to battery, load and vice versa.

1. Introduction

Increase in human population has elevated the power demand. In order to satisfy the power demand, fossil based energy source alone was utilized but, this has lead to pollution. Hence, the increase power demand can be met out using renewable energy sources. [1]-[3]. Solar electrical phenomenon cells are promising and gaining an excellent deal of attention, however, wattage generation from these sources is intermittent, looking on the climatic conditions. Thus, in tiny autonomous renewable energy systems, energy storage is needed therefore on extend the response rate and power capability of the power offer. The major challenge for implementing this technology is due to the unreliable power grid structure [4]. There are various methods to increase the effectiveness of the electrical power grid using renewable sources [5].

The inconsistency in radiation received from the sun demands for a tracking system to harvest the optimum power from the PV system for ensuring reliable operation. Hence, a charge control system becomes so vital to harvest the most available power for a given irradiation. This is important for regulating the battery as well as the load[6]. This work includes monitoring the ac and dc loads in the PV based autonomous system. This kind of system needs a secondary source like battery to supply energy to loads during off sunshine periods. Hence, to regulate the battery power, a kind buck boost converters is very essential. Inverters also become part of the autonomous system for delivering power to AC loads in
the system. Therefore, reliable power to the entire load in the system has been ensured by proper coordination among converters and inverters. [7],[8].

2. System Configuration and Modeling

![Block Diagram of Battery Management for Solar PV standalone System](image)

The standard configuration used for conventional solar Photovoltaic energy conversion systems (PVECS) has been shown in Figure 1. This includes an energy source in form of solar PV, converter block to regulate the DC, MPPT system to harvest the optimum power and essential loads. The generation side converter has been controlled with signals via maximum power point tracking (MPPT) system and the grid or load side converter. The loads in a system may be classified into DC and AC loads. Major portion of the loads is capable of performing well with DC power. But, some essential loads operation at high power is in need of AC power. Therefore, in an autonomous system even though the generated and stand by source are DC, it becomes so vital to incorporate an inverter to derive power to essential AC loads [9]. This approach is significant for autonomous system which comprises both DC and AC loads. The proper coordination between the two loads in view with available and back power along with necessary load priority is need of the day [10].

2.1 PV Array

A solar cell is a unit that changes radiation energy in form of light into electrical energy. In this cell the available energy in radiation is capable of emitting electron and that ensures the flow of dc current in the same. The solar cells in the electrical system or module are in charge of gathering radiation and converting it into electricity. Electrical system arrays are made up of a series of panels that are connected either in serial or parallel depends upon the system requirements [11].
Table 1. Parameter Specification of PV Module

| Parameters                                                      | Specification |
|----------------------------------------------------------------|---------------|
| Output power                                                   | 12.07 W       |
| Maximum Power point Current & Voltage                          | 7A & 1.8 V    |
| Short circuit current and Open circuit voltage                  | 8A & 21 V     |

2.2 Battery Design

Batteries are vital for many appliances for providing standby power. It is a unit that mostly converts a chemical energy into useful electrical energy. A battery comprises of cell and module. The rating of cell has been decided by its application. The most important function of batteries in an autonomous system is to store the generated power form the source and deliver the stored energy whenever needed. Lithium-ion batteries are getting more attention in PV based autonomous systems [12]. Since batteries seem to be vital, the way batteries are monitored is also important. This will help the system to operate the battery in a reliable and safe manner. Hence, a monitoring system to monitor the charge and discharge power of batteries will assist the autonomous system to deploy a control mechanism to switch ON and OFF the battery energy depends upon the requirement. The vital parameter of battery is considered for the control operation and it assures the safety of the battery[13]-[14].

Table 2. Parameter Specification of Battery

| Parameters             | Specification |
|------------------------|---------------|
| Battery Type           | Lithium-ion   |
| Nominal Voltage        | 24V           |
| Initial State of Charge| 50%           |
| Ampere hour rating     | 14Ah          |
| Fully Charged Voltage  | 28V           |

Initial state of charge is considered as 50% with respect to standard manufacturer specification on the purchase of any new battery that retains a charge of 50% or above. In practical applications, the SOC is not allowed to go beyond 50% and therefore the cell is recharged when the SOC reaches 50%.

Figure 2 depicts the methodology adopted in battery charge control system. The primary objective of the control system deployed for the batteries is to observe the terminal voltage and charge. In the initial observation if the charge available in the battery is at maximum level say 100% the battery is directed to maintain floating state [15]. On the other side, if the charge in the battery is less than the expected value, then the control system will direct the battery to charge either at constant voltage or current mode. In when the level of the voltage in the battery is lower than the stable voltage [16] then this condition has been utilized to estimate the MPPT charging position.
3. MPPT Control

Normally a solar cell is ready to convert solely 30-40% of the overall incident solar irradiation into power. Most electrical outlet chase (MPPT) is employed to boost the potency of a specific solar battery. Most electrical outlet chase (MPPT) is associate in rule that's won’t to extract the majority energy from PV under precise situations. The majority energy of a PV system relies on feature that includes irradiation, and other ambient conditions. Usually, a PV module produces most power voltage at cell temperature of 25°C. But on outside temperature it will fall or rise. MPPT checks the output of a specific PV panel and battery voltage decides the foremost economical voltage i.e., most electrical outlet voltage [17].

The principle of a power tracing scheme is applying correct resistance once sampling output of PV cell so as to get most power. MPPT is best in cooler conditions as a result of PV module works higher at cold temperatures. It is conjointly terribly effective once the battery is deeply discharged as a result of a lot of current may be extracted below low charge conditions [18]. MPPT devices square measure integrated with power physics making an electrical power convertor system in type of star inverters that convert DC power to AC power.

3.1 Perturb and Observe Method

Perturb and observe method is used in this standalone system which utilizes the panel voltage and current to carry computation. Solar battery has been periodically incrementing or decrementing for opening trackers. A voltage sensor alone has been used to sense the photovoltaic array voltage.
The implemented P & O MPPT scheme has been depicted in Figure 3. No scripting cope has been used and the functions of every block have been indicated. The PV array's voltage and current readings are fed into the P&O MPPT algorithm. A unit delay is utilized to run the earlier trial (K-1) function. The condition switch block handles the P&O algorithm's three if else conditions; the D block handles the duty cycle perturbation phase size. The task cycle increment and decrement function have been handled by a feedback loop D(K-1) which comprises of an adder and a memory block.

A limit unit D(K) maintains the duty sequence from getting too close to 0.4 or 0.6. The output from the controller in form of a duty cycle is linked as one of the inputs to charge controller of the battery unit while the other input to the charge controller is power associated with the PV. This is important to estimate the converter efficiency.

3.2 Boost Converter Design

![Figure 4.Circuit Diagram of DC-to-DC Converter (BOOST) used in simulation](image-url)
Several forms of converters may be utilized to act as regulators to improve the unrestrained DC voltage by changing the same into the required value as necessary for the system conditions. Every regulating converter system is in need of procedure that can switch devices to ON as well OFF based on the operating conditions. The kind of devices like IGBT or MOSFET may be selected with respect to system requirements and constraints. In this work IGBT has been selected to drive the converter elements used in the system. A suitable driving system is deployed for the same [19].

Figure 4 shows the arrangement of converter circuit considered in this work. The major elements of the same include a resistor acting as load, Capacitor, Inductor, diode and switches. Some form of driving scheme is necessary to drive the switches. This has been achieved by using PWM scheme of switching. This is important to regulate the designed voltage. This arrangement links PV system and storage battery and necessary load. The function of the control system deployed for the converter is to maintain the switches of the converter to ON or OFF so as to regulate the output voltage to the expected value. The diode used in the system will assist in driving the output according the condition of the switches. This will enforce the inductor and capacitor to supply the required power to the load.

3.3 Single Phase Inverter

The inverter deployed in the work is depicted in Figure 5. The inverter is framed to function in H bridge mode. This inverter model consists of full bridge scheme that is having IGBT as a switching device configured with two legs. Freewheeling diodes have been deployed for each switch to circulate the required current [20],[21].

![Circuit Diagram of Single-Phase Inverter](image)

**Figure 5. Circuit Diagram of Single-Phase Inverter**

The output voltage VAB is adequate to Vd while switching the S1 & S2. The required voltage at the output i.e., VAB is sufficient for voltage -Vd during switching ON of S3 & S4. Zero output voltage has been
obtained while the entire switches are turned ON. The upper and lower switches on each leg of the H-bridge alternately switch ON & OFF.

4. Result and Discussion

4.1 Subsystem of Solar PV with battery storage

Usually solar array utilizes 30-40% of the incident solar radiation to produce electricity. To get betterment in energy generation, power tracking scheme is essential. It is utilized by matching required source impedance and load impedance. Within the source side a lift converter is linked with solar array to reinforce the require voltage at the output. The source impedance gets matched with load impedance by appropriately changing the operating cycle of switches used in the converter.

4.2 Output DC Power

Figure 6 is the output voltage, current and power waveform obtained from MATLAB simulation for two different level irradiance (1000w/m², 600w/m²) and constant temperature (25 °C)

![Figure 6. Output result of solar PV](image)

It is observed that with decrease in incident irradiation at t=1sec, the number of charge carriers produced decreases, so the current falls drastically. This results in decrease in the power harnessed from the solar PV modules. The voltage however is subject to small fluctuations but remains almost constant because the number of charge carriers determine the amount of current through the load, but the potential difference depends on the electric field between the solar cell p-n junction.

4.3 Output of Battery

The Figure 7 shows that the output voltage of battery across the time (1s) starts decreasing and remains at 25.6v. Hence, it is observed that output of battery terminal voltage increases with increase in irradiation.
Figure 7. Output of Battery

4.4 Output Voltage of DC Load
The DC power obtained from the panel is fed to inverter for converting into ac power for feeding ac load which is output voltage of single-phase resistive load shown in Figure 8.

Figure 8. DC Voltage across Load

4.5 Output Current of DC Load
The DC power obtained from the panel is fed to inverter for converting into ac power for feeding ac load which is output current of single-phase resistive load shown in Figure 9.
The DC load voltage and current waveforms are almost constant with minor ripples within the standard error limits. Change in illumination at $t=1$ sec causes a spike in both voltage and current waveforms, however the boost converter stabilizes and compensates for the changes to retain the output constant.

5. Conclusion

The model presented is designed and simulated using MATLAB. A 1KW photovoltaic standalone system has been developed using MATLAB Simulink. This model is framed around required tracking for utmost utilization of energy. The MPPT is governed by the P & O algorithm, and the output results of voltage, current and power waveforms across various units are presented with respect to time. The algorithms improve the dynamics and steady state performance of the photovoltaic system. This further improves the efficiency of the DC-DC converter system. The proposed system also stabilizes the terminal voltage of the battery used in the system for changing irradiation. The State of Charge (SOC) of the battery is monitored for efficient utilization of remaining energy in the battery, as the discharging takes place based on system requirements. In this scenario, the performance of the Lithium-ion battery offered a good charge and discharge profile with high power density meeting the requirements of the system in an efficient manner.

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