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Hardware Implementation of Photovoltaic System using Boost-SEPIC Converter with Direct Control IC MPPT Algorithm

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Abstract

This paper proposes a regulated DC power supply through photovoltaic panel for DC application. The system is composed of PV panel, Maximum power point tracking controller using boost converter and voltage regulator. The IC MPPT control algorithm aims to extract maximum power from the PV array and regulate the obtained voltage using the DC-DC SEPIC converter. In this paper, the fixed step size incremental conductance with direct control was employed. The PI control loop is abolished and the duty cycle is fitted directly in the algorithm. To commensurate the absence of PI controller in the proposed system, a small marginal error was allowed. The DC – DC SEPIC converter acts as the voltage regulator and regulates the voltage from the supply to the load. The regulated output voltage is obtained under varying load and temperature conditions. The designed operating system supplies the DC power and charge the battery during PV power generation. The hardware result of the proposed system shows that the voltage is regulated at 53.8V under varying load and environmental conditions. The efficiency of the system is increased and the cost also reduced with low power loss.

Keywords: *Battery storage alone system, maximum power point tracking algorithm (MPPT), photo-voltaic (PV), SEPIC converter, voltage regulation.*

1. Introduction

The increasing demand for low cost energy and growing concern about environmental issues, photovoltaic based systems are being increasingly employed in diverse applications both at domestic and commercial levels [1]. The major problem of nonlinear current verses voltage characteristic limits its applications. Due to this limitation it is difficult to extract available maximum power from the PV system. To extract available maximum power many maximum power point tracking (MPPT) algorithms have been proposed in the literature. The application of PV systems can be phrased into standalone system and grid connected system [2]. The standalone system is widely used in remote areas where access to electricity is not viable. The standalone PV system can provide regulated load voltage and the reliability of the system cannot be justified [2]. Storage batteries are advised to improve the reliability of the standalone systems [4]. A fair amount of literature [3], [4], [6]-[7] has dealt with the operation of hybrid systems. In some hybrid systems [4], [5], the batteries are used to compensate the mismatch between the components and the load. The size of the battery can be reduced when a battery charging circuit is inserted between the DC bus and the battery [6], [8]. In literature, no more attention has been laid on the PV Systems with DC loads. The leading process on energy savings has increased the usage of light emitting diode based street lights, electronic chokes, compact fluorescent lamps etc. The PV system stacked as an energy resource can be used for the DC loads to be connected directly to the DC bus. However the PV system with MPPT controller cannot generate the constant DC voltage as the output voltage from the various MPPT algorithms varies with the load and the environmental conditions. An attempt was made in [9] to provide reliable power to the loads connected at the DC side, yet in this case the PV power is not utilized effectively [10]. When the generated PV power is more than the load demand, only the load power demand is met by the PV and the excess PV power is not fed to the grid [11]. This generated extra power can be stored in rechargeable battery or can be transferred to the grid. When a battery is used, proper charging circuit is needed [12]. There are many topologies available in the literature which can control the charging of the battery [14]-[16]. Shunt regulator along with the battery can be used to regulate the voltage in the DC bus. [13].

Most of the literature [15]-[18] is deals with the solar power supplies but they do not put emphasis on the output voltage regulation. A DC-DC converter can be used for regulated power supply to obtain constant voltage. The selection rating of converter depends upon the input and output voltage rating. A comparative study of different converters is available in [19]. SEPIC can be used for power supply due to its several advantages [19]-[20]. The proposed system in this paper consists of the power source, DC load, two DC-DC converters and a power engagement control system to control the operation and power flow control in the system. The system acts like a regulated uninterrupted power supply for a DC load. The proposed system is illustrated using the simulation study through MATLAB software.

2. Circuit Configuration

Fig. 1 shows the block diagram of the proposed voltage regulation system which consists of two DC to DC converters. The boost converter connected between the PV array and the DC bus is used for the MPPT control and to boost the lower voltage of the PV cell [13], [17]-[18]. The SEPIC converter is used between the DC bus and the load for voltage regulation as it has capability to step-up and step-down the input voltage.

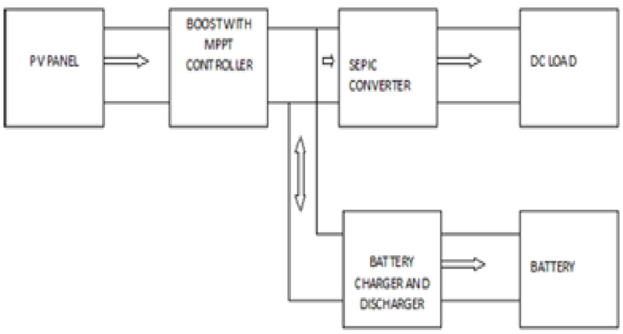

Fig.1. Block diagram of the proposed system.

3. Control Strategy

The control strategy in the PV system is divided into three parts.

3.1 Voltage Regulation

The SEPIC converter is mainly used for voltage regulation. The converter mentioned here is having the similarity to the buck-boost converter that has the capability to both step-up and step-down the input voltage with no change in the voltage polarity. It possesses right-half-plane zero in the continuous conduction mode with the peak-current-mode control in the output voltage regulation mode [22]. The averaged switch modeling technique is presented in [22].

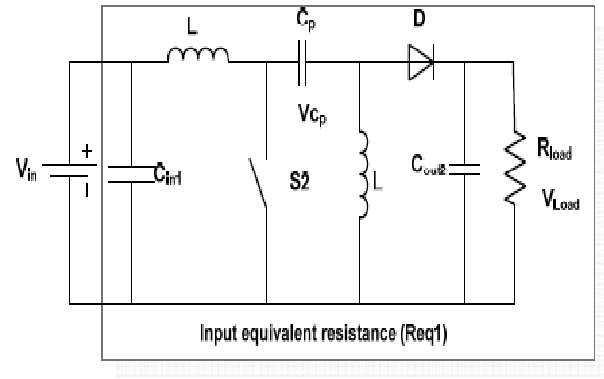

Fig 2. SEPIC converter

The output transfer function of the SEPIC converter in the CCM with output voltage regulation can be derived from Fig. B in the following form.

D2 is the duty ratio of the SEPIC converter. The relationship between the input equivalent resistances to load resistance can be derived from Fig.2 as follows.

The SEPIC converter is shown in this paper through an open loop control.

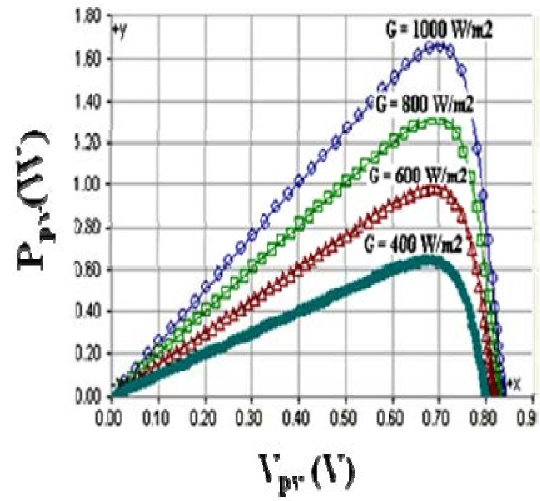

Fig 3. Power Vs Voltage characteristics of a PV cell

A boost converter is used in-between the PV module and the DC bus to derive the maximum power. The Circuit diagram of the boost converter is shown in Fig. 4.

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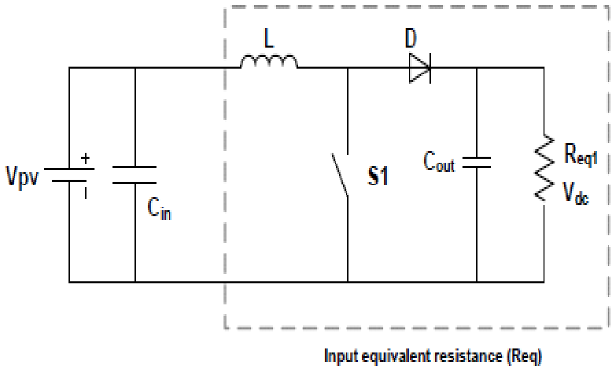

Fig. 4. Boost converter control

Here it shows the controller is used to control the output voltage of PV module. The MPPT controller gives the reference voltage (V_{ref}) for the boost controller to be modeled.

3.2 Direct Control Method

In general, the Conventional MPPT systems have two independent control loop mechanism to control the MPPT. The first loop control contains the MPPT algorithm; it usually has a proportional or P–Integral controller. The Incremental Conductance method is to obtain the use of instantaneous and Incremental Conductance algorithm to generate an error signal mainly is obtained as zero at the MPP. Most over it should not be zero at most of the operating points. The purpose over the second control loop is to make the error from MPPs near to zero. However the simplicity of operation and the ease of design with the inexpensive maintenance and the low cost module made the PI controllers become more popular in the linear systems. Hence the MPPT system of standalone photovoltaic is a non-linear control problem due to the non-linearity nature of photovoltaic and environmental conditions. PI controllers do not generally work well. In this paper, the Incremental Conductance method with direct control is selected. The Proportional integral control loop is eliminated, but the duty cycle is adjusted exactly in the algorithm. The control loop is less complex and the computational time for tuning controller gains is eliminated. To commensurate the absence of PI controller in the proposed system, a small marginal error was allowed. The purpose of this paper is to eliminate the second control loop system and to show that deceptive MPPT methods may not necessarily obtain the best results, hence engage them in a simple manner for complicated electronic project is to be considered. The Probability of the proposed system is investigated with a dc to dc converter configured as the MPPT. It generates the pulse-width modulation waveform to fully control the duty cycle of the converter switch according to the Incremental Conductance algorithm.

3.3 PV Module

The basic structural unit of a solar module is the PV cells. A solar cell converts energy in the photons of sunlight into electricity by means of the photoelectric phenomenon found in certain types of semiconductor materials such as silicon and selenium. A single solar cell can only produce a small amount of power. To increase the output power of a system, solar cells are generally connected in series or parallel to form PV modules. PV module characteristics are comprehensively discussed, which indicate an exponential and nonlinear relation between the output current and voltage of a PV module. The main equation for the output current of a module is

$$I_{ph} = [I_{scr} + k_i (T - T_r)]\ S\ 100 \text{ --------------------- } (1)$$

Where

I_{scr} short-circuit current at reference temperature and radiation;

k_i short-circuit current temperature coefficient;

T_r cell reference temperature;

S solar irradiation in milli-watts per square-centimeter.

Hence the cell reverse saturation current is being computed.

3.4 MPPT Control

The Fig. 3 shows the PV Power verses PV voltage characteristics of a PV cell by keeping the radiation constant. The boost converter along with the MPPT controller can track the maximum power point tracking (MPPT) of the PV cell. Incremental Conductance MPPT technique is used as a generalized MPPT algorithm [10]. Flow chart of the IC MPPT is shown in Fig. 5.

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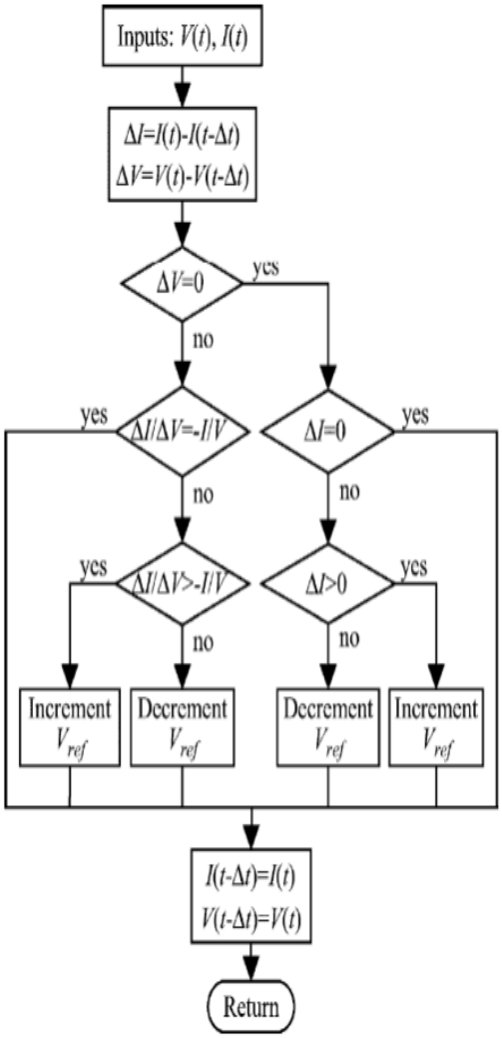


Fig. 5. Flowchart of IC MPPT algorithm

$$R_{eq} = R_{eq1}\ (1- D_1)^2 \text{---------------------------}(2)$$

Where D_1 and D_2, the duty ratio of boost and SEPIC converters respectively.

$$R_{eq} = R_{load}\ \underline{(1- D_2)^2\ (1- D}$$
$$D^2 \quad \text{----------------------}(3)$$

From the above equations, the PV module acts like a short circuit if the duty ratio of the converter becomes unity.

The most sequential Charging and discharging of the battery depends upon the power generation by the boost converter and power requirement by the load P_{load}. When generation power P_{pvou} exceeds the load demand power P_{load}, then the charging process will start depending upon the battery voltage V_{bat} and battery state-of-charge.

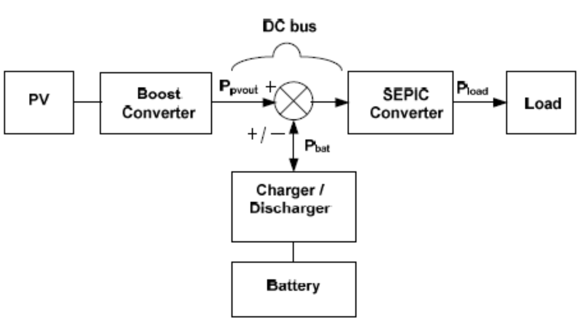


Fig 6. Energy flow diagram of whole system.

From the constant voltage-charging mode, a constant voltage is applied across the battery depending upon the battery manufacturer regulation. The initial current will be of very large for constant voltage-charge mode, hence the high temperature due to the current may damage the battery. Hence the current during the entire process of charging is limited.

The obtained current using the constant current-charging mode is fully dependent upon the external reference and the absorbed energy, henceforth it can adjust the output energy of the PV cell and the constant current-charging mode is the most suitable choice for the entire PV system.

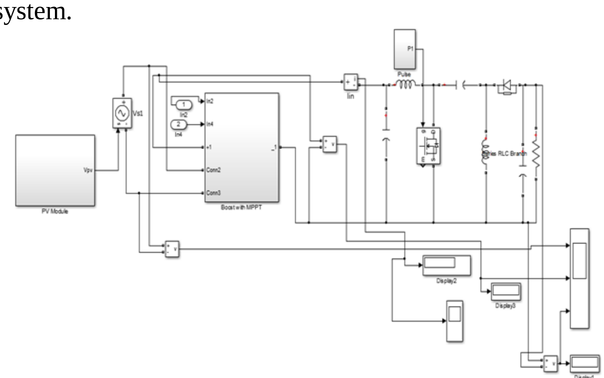


Fig.7. Simulation diagram of the proposed system.

Here the constant voltage-charging mode and the constant current-charge mode are clearly shown. From which ‘u’ is the battery voltage and ‘i’ is the battery current. During the initial charging process, the battery uses the charge current limiting characteristics of the charging circuit. After the battery is being charged, the terminal voltage of the battery rises to the determined level. This paper shows a constant current charging mode is used, which will be converted to constant voltage-charging mode as early as the voltage achieves to a certain level [21–23].

Hysteretic current loop control is used in the constant current-charging mode. By considering the above ideal output current waveform as the command signal and the above actual current waveform as the original feedback signal. Hence the actual output current changes with respect to the command signal changes.

Henceforth the constant-voltage charging mode is achieved through the two loop level control mechanism. Put the voltage of the battery as the control reference V_{ref}

and the affirmative voltage of the battery as the desired value in the constant-voltage charging mode.

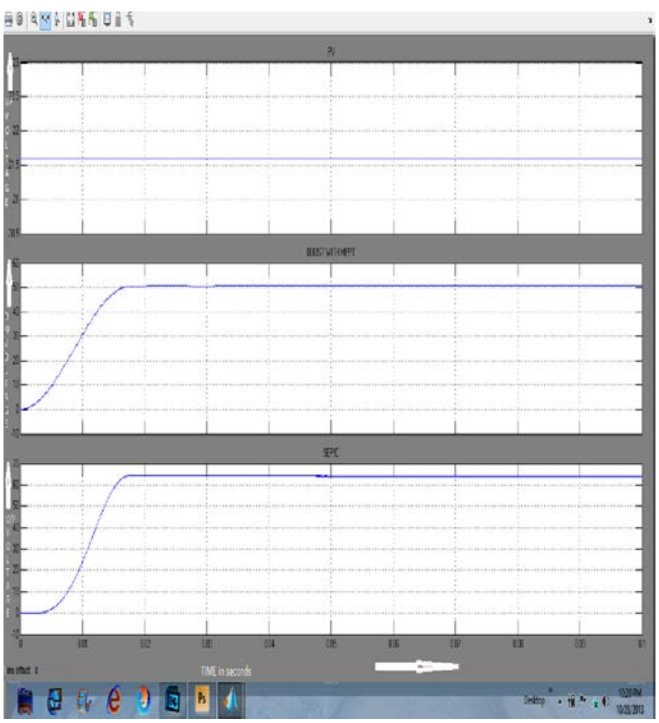
Battery will start to become discharging when the load demand P_{load} minimize the losses in the SEPIC converter η is high as compared with the PV generation power P_{pvout} and the battery SOC is greater than the minimum allowable value of SOC (SOC_{min}). During the discharging period, the battery is directly connected to the DC bus.

4. Simulation Result

According to voltage regulation control strategy proposed in this paper, simulation models are built based in the MATLAB platform. The performance of the voltage regulation and battery charging, discharging control is verified through the simulation study.

Fig.8. Simulation result of the proposed system.

The model is designed for regulated 64 V DC output and the load resistance is varied from 5KΩ to 50 KΩ. The peak power of the PV panel is 750 W. The battery is taken such that during simulation time it can accumulate the power.



4.1 Under Varying Environmental Condition

When environmental conditions like temperature, solar radiation changes, the PV output power also changes. Fig. shows the simulation result of the proposed system under varying environmental conditions. It is seen that despite the changes in the environmental conditions, the load voltage is regulated at 64V DC is shown in Table 1.

Sl No	**Solar Radiation (W/m2)**	**Load Resistance (R Load) (k Ω)**	**Load Voltage (VLoad) (V)**
1	**200**	**50**	**63.5**
2	**400**	**50**	**64**
3	**600**	**50**	**64**
4	**800**	**50**	**64**
5	**1000**	**50**	**64**
6	**1200**	**50**	**64**

TABLE.1.SIMULATION RESULTS OBTAINED UNDER VARYING ENVIRONMENTAL CONDITIONS

4.2 Under Varying Load Condition

The proposed system is tested under varying load conditions by varying the load resistance. The simulation result of proposed voltage regulation system under varying load condition is shown in Table.2. It is observed that the output voltage regulates around 64V DC despite the changes in the load.

Sl No	**Solar Radiation (W/m^2)**	**Load Resistance (R Load) (k Ω)**	**Load Voltage (VLoad) (V)**
1	**1000**	**5**	**63.5**
2	**1000**	**10**	**64**
3	**1000**	**15**	**64**
4	**1000**	**20**	**64**
5	**1000**	**25**	**64**
6	**1000**	**30**	**64**
7	**1000**	**35**	**64**
8	**1000**	**40**	**64**
9	**1000**	**45**	**64**
10	**1000**	**50**	**64**

TABLE .2. SIMULATION RESULTS OBTAINED UNDER VARYING LOAD CONDITIONS

5. Hardware Implementation

The output diagram of the Photovoltaic system show the output voltage of 18.35V is obtained. Fig 9 shows the Output voltage of the PV system.

Fig.9. Output voltage of the PV system

The proposed system shows that the voltage is regulated at 53.8V under varying load and environmental conditions. Fig 9 shows the hardware results of the proposed system.

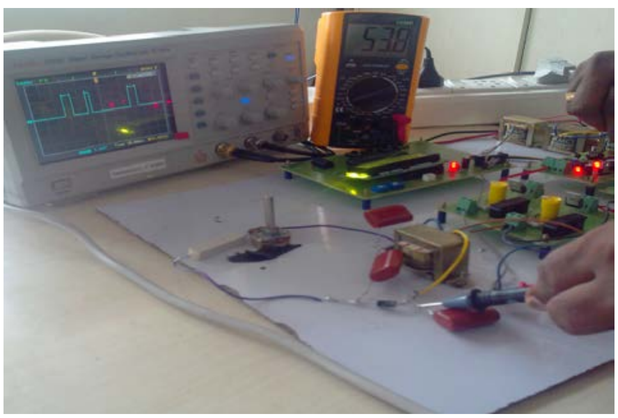


Fig.10. Hardware result of the proposed system

6. Conclusion

In this paper, SEPIC Converter is used for the purpose of voltage regulation. The MPPT Algorithm is used to track the maximum power from the PV Systems. Here the fixed size incremental conductance maximum power point tracking algorithm is used to track the maximum power from the PV Systems. The boost converter is used to boost the input voltage from the PV to the maximum level and it is given as input voltage to the SEPIC Converter and to the battery system. It also helps to improve the system performance of the current system in case of high efficiency, maximum power and maximum voltage. This works includes the design of the stand alone photovoltaic system which includes the PV array model, boost converter, SEPIC converter, battery charger and discharger and the DC load. The model is designed for regulated 64 V DC output and the load resistance is varied from 5KΩ to 50KΩ. The peak power of the PV panel is 750 W. The battery is taken such that during simulation time it can accumulate the power. The hardware result of the proposed system shows that the voltage is regulated at 53.8V under varying load and environmental conditions.

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