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Partial Power Processing Boost Converter with MPPT Control for PV Systems

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Abstract: ***DC/DC converters which form interface between photovoltaic panels and the batteries/inverters is an integral part of any photovoltaic power plant. These converters regulate the charge provided by PV panels to the batteries/inverters. Therefore in this work, for PV architectures, DC/DC converter with partial power processing technique is proposed. This proposed topology is said to have the advantage of simplicity, high efficiency, low cost and high reliability. The high efficiency of the converter output will be achieved by having the input PV power fed forward to the output without being processed and only a portion of the PV power is processed by the converter depending on the voltage regulation requirement. Here Peturb and Observe MPPT controller algorithm will be used for locating maximum power points, at any sunlight conditions for extracting the maximum power from the PV module and transferring that power to the load. The performance of the proposed topology is analyzed with the help of MATLAB/Simulink model.***

Keywords: Photovoltaic (PV), Maximum Power Point Tracking (MPPT), partial power processing technique, Peturb and Observe (P&O) algorithm, boost converter

1. Introduction

The rapid growth in the demand for electricity has led to the extensive use of conventional energy resources such as fossil fuels to meet the increasing demand. This has resulted in adverse changes in the environmental conditions such as global warming, depletion of conventional energy resources, etc. This led to the search for new energy source that is cheaper, convenient and sustainable. Solar energy has offered promising results in the quest of finding the solution for the problem.

Photovoltaic power generation has an important role to play due to the fact that it is a green source, clean, non polluting, renewable, energy with a long service life and high reliability. The field of photovoltaic array (PV) has experienced a remarkable growth for past two decades in its widespread use from standalone to utility interactive PV systems.

Despite all these advantages of solar energy, they do not present desirable efficiency. The efficiency of solar cells depends on many factors such as temperature, irradiation and spectral characteristics of sunlight; dust, shading, which result in poor performance. In addressing to the poor efficiency of photovoltaic systems, various methods were proposed among which a concept called “maximum point power tracking” (MPPT) is explored.

Using a solar panel or an array of panels without a controller that can perform Maximum Power Point Tracking (MPPT) will often result in wasting of the power. The photovoltaic cell has an optimum operating point called the maximum power point (MPP) to be tracked to extract the maximum power. An efficient MPPT algorithm is important criteria to increase the efficiency of PV system to maintain the PV array’s operating point at its MPP at all environmental conditions. The variation in solar irradiation and temperature causes the tracker to deviate from the maximum power point, thus the tracker needs to response within a short time to these variations to avoid energy loss. The operating point of the PV is dynamically modified by the controller so as to operate at the maximum power point at any sunlight conditions and maintain PV power in the neighborhoods of this point to produce maximum possible power and to achieve higher efficiency. A variety of maximum power point tracking methods are developed. Here in this work we are using Peturb and Observe MPPT algorithm to track the MPP.

For implementing the MPPT, there is a need to include the dc-dc converter into the system. Whatever the weather (irradiation and temperature) and the load conditions, the control system of the converter will ensure the operating point is optimized for maximum power transfer. A dc/dc converter serves the purpose of transferring maximum power from the solar PV module to the load. It acts as an interface between the load and the module.

One of the key factors affecting PV system design is the proper selection and design of the dc/dc converters used in these architectures. In this work, a high efficient partial power processing dc/dc boost converter is presented for use in the PV systems. The major considerations while designing solar power converter include efficiency, reliability and cost. Therefore this work aims at increasing the efficiency, reliability and power output of the system. These objectives are tried achieved through the design of partial power processing dc/dc boost converter with MPPT controller and the designed models are simulated using MATLAB/Simulink.

This paper is organized as follows. Section 2 presents brief outline of solar energy, PV system and MPPT technique. In Section 3, partial power processing boost converter operation is given. In Section 4 simulation circuits and results are discussed. Finally, Section 5 contains concluding remarks.

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2. Preliminaries

2.1 Solar Energy

Among the renewable and environmental friendly energy sources Sun's solar radiations plays the most significant role, which has the highest potential in the future as heaters, photovoltaic and solar-hydrogen energy alternatives [1]–[3]. Solar energy systems are recognized as a primary technology in the medium and long term energy sources which is capable of reducing global warming and climate change impacts. Solar energy is a non-conventional type/renewable type of energy. Energy from sun (solar energy) reaches the earth in the form of electromagnetic radiations. To harvest the solar energy, the most common way is to use photo voltaic panels which will receive photon energy from sun and convert it to electrical energy.

The quantity of solar energy (W/m^2) at normal incidence outside the atmosphere (extraterrestrial) at the mean sun-earth distance is called solar constant. Its mean value is 1367.7 W/m^2. The formula which is used to calculate solar energy received by earth is given by
$E=3.6*(10^{-9})*S*n*r^2$ (1) where, E is the solar energy in EJ.
S is the Solar Constant in W/m^2.
n is the number of hours.
r is the earth radius in km.

The comparison between different photovoltaic cells can be done on the basis of their performance and characteristic curve. The parameters are always given in datasheet. The datasheet make available the notable parameter regarding the characteristics and performance of PV cells with respect to standard test condition (STC).

Standard test conditions are as follows:
Temperature = 25^0C
Irradiance = 1000 W/m^2
Spectrum of x = 1.5 i.e. Air Mass (AM).

2.2 Photovoltaic System

A photovoltaic system is a system which uses one or more solar panels to convert solar energy into electricity. PV cells convert sunlight directly into electricity without creating air or water pollution. PV cells are made of at least two layers of semiconductor material. One layer has a positive charge, the other negative. When light enters the cell, some of the photons from the light are absorbed by the semiconductor atoms, freeing electrons from the cell's negative layer to flow through an external circuit and back into positive layer. This flow of electrons produces electric current. The PV cell working is shown in Fig. 2.2.1.

To increase their utility, dozens of individual PV cells are interconnected together in a sealed, weatherproof package called a module. When two modules are wired together in series, their voltage is doubled while the current stays constant. When two modules are wired in parallel, their current is doubled while the voltage stays constant. To achieve the desired voltage and current, modules are wired in series and parallel into what is called a PV array.

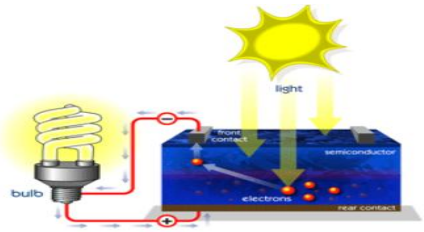


Figure 2.2.1: PV cell working

To increase their utility, dozens of individual PV cells are interconnected together in a sealed, weatherproof package called a module. When two modules are wired together in series, their voltage is doubled while the current stays constant. When two modules are wired in parallel, their current is doubled while the voltage stays constant. To achieve the desired voltage and current, modules are wired in series and parallel into what is called a PV array.

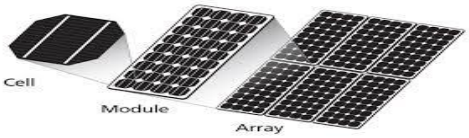


Figure 2.2.2: PV cell, module, array

The general equivalent circuit of a single PV cell and its PV-IV characteristics [4]-[6] are as shown in the Fig. 2.2.3. and 2.2.4. respectively.

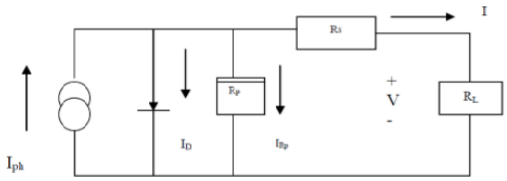


Figure 2.2.3: Equivalent circuit of a PV cell

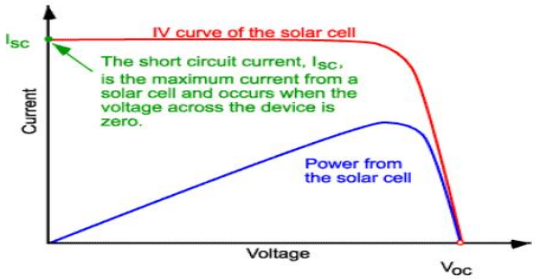


Figure 2.2.4: PV - IV characteristics of a PV cell

2.3 Maximum Power Point Tracking

Maximum power point tracking, frequently referred to as MPPT, is an electronic system that operates the PHOTOVOLTAIC module in a manner that allows the modules to produce all power they are capable of [7]-[8]. MPPT is a fully electronic system that varies operating point of the modules so that the modules are able to deliver maximum available power. The main application and

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benefits of maximum power point (MPPT) in solar power system is to increase the efficiency and power of solar cells and help to enable them to be competitive solution in an increasingly energy market.

By operating a solar panel or array of panels without MPPT controller results in wastage of power and hence lower efficiency of solar panel/array, which ultimately requires installing more panels. Maximum power point controller is used in PV system to force the PV module to operate at its MPP to produce maximum power output. To overcome the disadvantages of higher installation costs and low energy conversion efficiency, MPPT controllers are used in PV systems. Most modern MPPT"s are around 93-97% efficient in conversion. The gain can vary widely depending weather, temperature, battery state of charge or load condition and other factors. We typically get a 20-45% power gain in winter and 10-15% power gain in summer. MPPT's are most effective under these conditions: Winter, and/or cloudy or hazy days - when the extra power is needed the most. Fig.2.3 shows the PV and IV curves along with the MPP point.

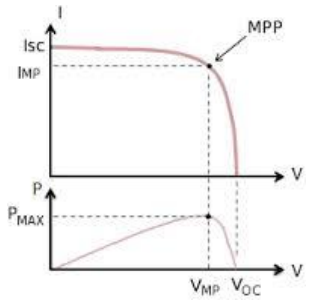


Figure 2.3: PV and IV curves along with the MPP point.

Maximum power point trackers may implement different algorithms [9]. A peturb and observe MPPT algorithm is used in this work for locating maximum power points. In this method the controller adjusts the voltage by a small amount from the array and measures power; if the power increases, further adjustments in that direction are tried until power no longer increases. This is called the perturb and observe method and is most common, although this method can result in oscillations of power output. Perturb and observe is the most commonly used MPPT method due to its ease of implementation. Perturb and observe method may result in top-level efficiency, provided that a proper predictive and adaptive hill climbing strategy is adopted.

3. Partial Power Processing DC-DC Boost Converter

The dc/dc converter chosen in this work for PV system is the partial power processing boost converter whose block diagram is as shown in Fig.3.1. The efficiency of dc/dc converters can be improved by means of using partial power processing dc/dc converter as in Fig. 3.2 (a), or a multichannel interleaved converter structure as in Fig. 3.2(b).

The converter is composed of two interleaved channels to reduce input current ripple. The converter has a very simple topology composed of only one switching device and one diode per channel. In these converters, part of the input power is directly fed forward to the output, thus achieving close to 100% efficiency, and the remaining part of the power processed by the converter depends on the voltage difference between the PV side and dc-link voltage.

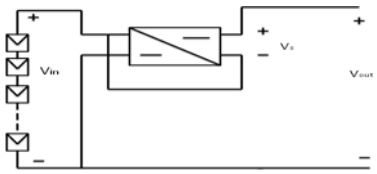


Figure 3.1: Proposed partial power processing structure.

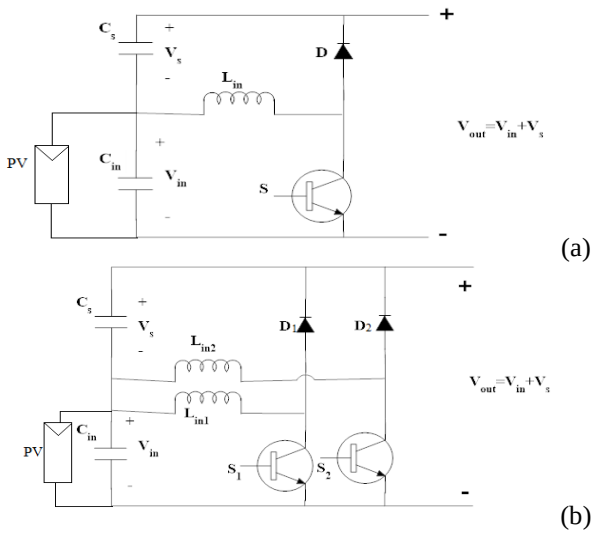


Figure 3.2: Partial power processing boost dc/dc converter (a) one channel; (b) two channels.

The fraction of the input power processed by the converter is given by,

$$\text{Power Processed} = \left(\frac{\frac{Vs}{Vin}}{\frac{Vs}{Vin}+1}\right) \quad (2)$$

Thus, in this topology the output voltage is sum of the PV string voltage and the voltage of the output capacitor. Therefore, the dc/dc converter need not have excessively high efficiency over its operating range to achieve overall high conversion efficiency. Efficiency is also maximized by operating only one of the two interleaved channels at light loads. Further, at very light load conditions the converter can be operated in discontinuous conduction mode to reduce device turn on losses. The classical partial power processing converters included high frequency transformers in their design. The proposed topology does not require a high frequency transformer, which simplifies the design and reduces the required converter cost.

The operation of this converter is similar to that of a simple boost circuit. The modes of operation over a switching period T are shown in Fig. 3.3 and are explained as follows:

Mode I (0< t < dT): In this stage, switch (MOSFET/IGBT), S is turned ON and the inductor current builds up

$$L_{in}\frac{di_{Lin}}{dt} = V_{in} \quad (3)$$

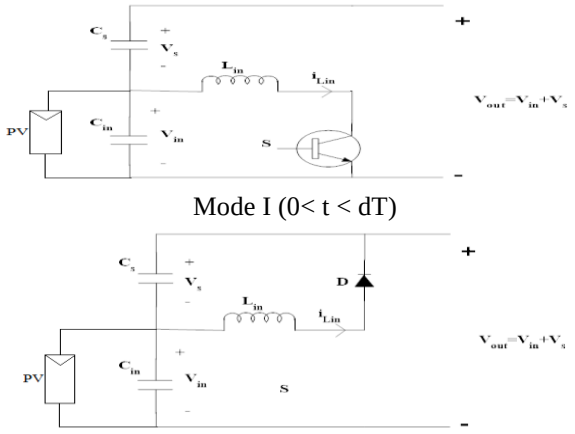
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$$C_s \frac{dV_s}{dt} = -\frac{V_s+V_{in}}{R_{Load}} \quad (4)$$

Mode II (dT < t <T): The switch S is turned OFF and the inductor current is diverted to the diode (D) where the energy is discharged into the capacitor Cs. For a continuous conduction mode the cycle ends at this stage.

$$L_{in}\frac{di_{Lin}}{dt} = -V_s \quad (5)$$

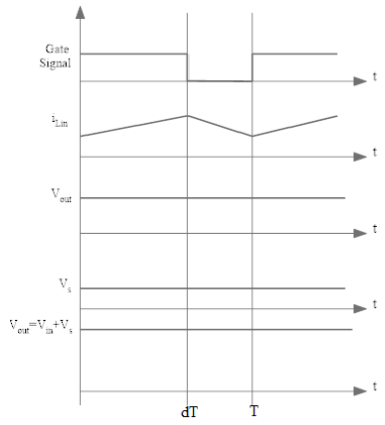
$$C_s \frac{dV_s}{dt} = i_{Lin} - \frac{V_s+V_{in}}{R_{Load}} \quad (6)$$



Mode I (0< t < dT)

(a)

Mode II (dT < t <T)



(b)

Figure 3.3: (a) Modes of operation of the partial power processing dc/dc converter in CCM (Continuous Conduction Mode) and (b) the corresponding timing diagram.

4. Simulation Circuits and Results

To verify the validity of the proposed partial power processing dc/dc boost converter with MPPT control, the well-known software MATLAB R2013b was adopted to carry out the simulation process.

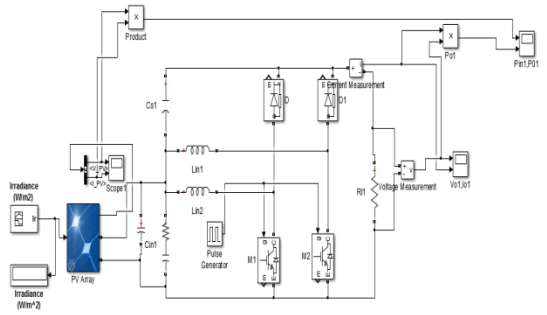
A 380W, 30 kHz, two channel dc/dc converter (with and without MPPT) simulation circuit connected to a PV system (with PV module BP Solar SX3190) is as shown in Fig.4.

Converter component values are listed in Table I.

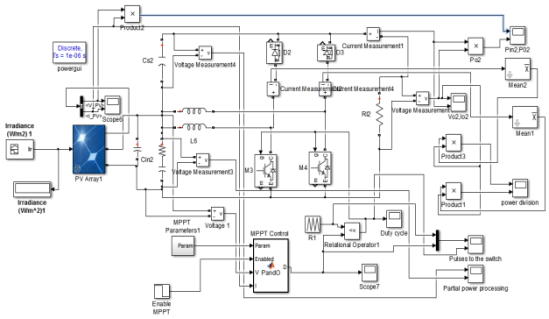
Table 1: Converter components

Parameters	*Values*
Rated power	380W (190 W / channel)
Switching frequency	30 kHz
V_{in}	24 V
C_{in}	460 µF
C_s	230 µF
L_{in1}, L_{in2}	2000 µH
R_L	14.5 Ω

The simulatin circuits shown in the Fig.4. are simulated. The simulation results are as follws:



(a)



(b)

Figure 4: Simulation circuit of partial power processing boost converter connected to PV array. (a) without MPPT (b) with MPPT

The circuit is simulated for four different irradiance conditions as shown in Fig.4.1. The I-V and P-V curves for the BP Solar SX3190 module and the array are as shown in Fig.4.2.

The partial power processing of the proposed boost converter for an input voltage of 24V is clearly indicated in the Fig.4.5, where the input voltage of 24V is fed forward to the output without being processed (V_{in}) and remaining part of the voltage of nearly 50V (V_s) is processed by the converter depending on the voltage regulation (i.e. difference between the input side and the dc link side) requirement. Thus the converter need not have very high efficiency over its operating range to achieve overall high efficiency also reducing the size of the components required and hence the cost.

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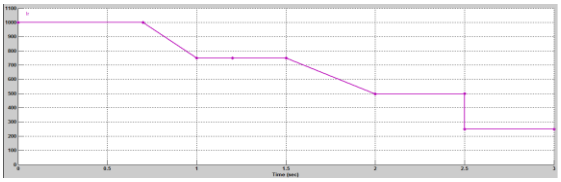
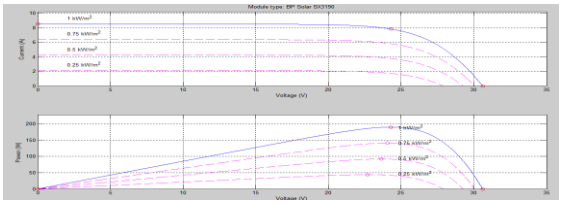
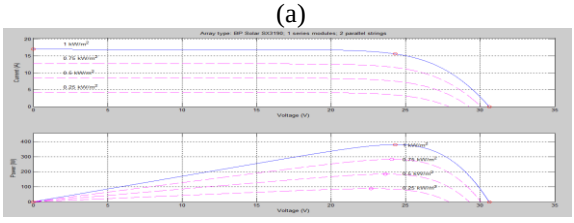


Figure 4.1: Irradiance input for PV array



(a)



(b)

Figure 4.2: I-V and P-V plots for various irradiance for BP Solar SX3190. (a) single module (b) array

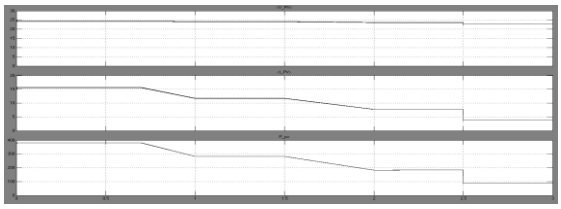


Figure 4.3: PV output voltage, current and power

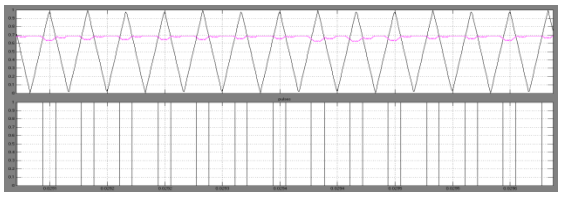


Figure 4.4: Pulses to the switches in the channels

The Fig.4.6 shows the power distribution between the two channels where each channel near equally carry half of the total output power. Thus when the two channels in parallel are switched ON the input current will be divided equally between the two channels resulting in each channel carrying near half the rated power and thus even during the failure of any one channel the other channel will still be able to carry the required power and thus increasing the reliability of the system. When the input power falls less than 50% of the rated then one of the channel can be turned OFF and thus eliminating all the associated switching losses and improving light load efficiency.

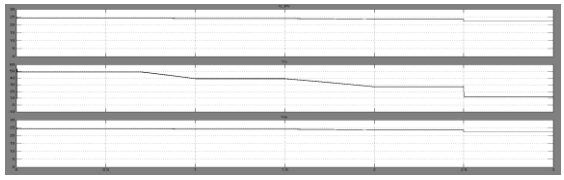


Figure 4.5: Figure showing partial power processing of proposed boost converter

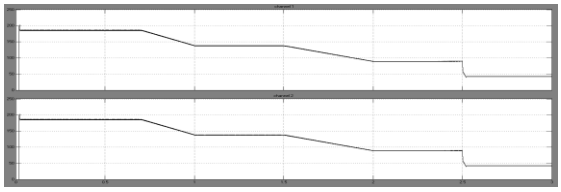


Figure 4.6: Power processed by channels 1 and 2

For the various irradiance conditions the PV and the converter (with and without MPPT) power output are as shown in the Fig.4.7

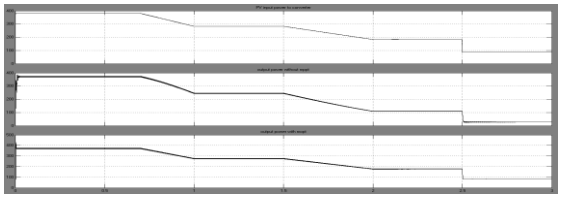


Figure 4.7: Power output of the PV array and the converter for various irradiance conditions

It can be easily noticed from the Fig.4.7 that output power from the converter without MPPT at various irradiance conditions is much lower than that obtained through the use of MPPT. Also the power output from the system with MPPT is nearly same as the power at MPP for particular irradiance condition as indicated in P-V plot of Fig.4.2.b, thus upholding the fact that the use of MPPT controller increases the operating efficiency of the PV system by making the system to operate at maximum power point.

5. Conclusion

A simple, high efficient dc/dc converter with MPPT control employing Peturb and Observe algorithm suitable for medium to large scale PV systems is proposed. High efficiency of the converter is achieved by means of partial power processing also by the coordinated operation of the interleaved channels of the converter. Also overall efficiency of the plant was seen improved through the use of MPPT. The reliability was seen improved through the interleaved channel design of the converter. The proposed converter was simulated for testing of performance parameters including the efficiency, reliability, switching operation, MPPT performance and parallel operation. Simulation results show excellent performance and fulfillment of the work objectives.

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