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High Efficiency Interleaved DC-DC Converter for PV Applications

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Abstract: **Interleaved Boost converters (IBC) serve a number of applications, which require a boost in the output voltage such as the distributed generators (DG´S), high voltage battery chargers etc. This paper brings out the design and simulation of a high efficiency two-phase interleaved DC-DC converter with an efficient MPPT controller. The configuration of interleaved boost converters comprises parallel combination of a number of boost converters with phase shifted PWM signals. The advantages of interleaved boost converters compared to conventional boost converters are reduction in output ripple voltage, ripple current and high efficiency. The current ratings of switching devices are considerably reduced due to the high frequency operation, which in turn helps in the reduction of overall cost. The performance parameters of the proposed interleaved boost converter are analyzed by MATLAB simulation.**

Keywords: Interleaved Boost Converter(IBC), Distributed Generators(DG´S), Maximum Power point Tracking (MPPT)

I. INTRODUCTION

Today, the world trend is to find a non-depletable and clean source of energy. Solar energy is the most effective and harmless source available to us. It is considered as one of the most promising source of energy due to its enormous abundance. Solar PV technology has seen unparalleled growth in the last few decades.Solar PV technology finds several applications in different fields. One of the main challenges of PV technology is the lower voltage output from the panel of a specific rating. The development of an efficient DC-DC converter assumes importance on this ground. Interleaved Boost Converter has the boost and current sharing capability on high power application. It can be configured with many phases that allow the input current sharing and heat dissipation. Even though there are a number of DC boost converters that are available for the PV applications, they have high amount of ripples. In addition to the minimization of the ripples, interleaved boost converters have higher modularity, reliability and power capability at the cost of additional inductors, diodes and switching devices. The two phase interleaved boost converter can be used with PV so as to get reduced current ripples.

The robot receives the data and tracks to that particular coordinate with the help of GPS. The robot has a central AVR microcontroller which controls and coordinates all the activities of the robot, and a dedicated 8051 micro controller for the GPS control. Once the robot reaches the zone, using This paper will first explain the basic principle of Photovoltaic cell. Next, the operation and simulation of interleaved DC-DC converter are obtained. The simulation results are also presented.

II. PHOTOVOLTAIC CELL

PV cell is configured as a large area p-n junction made from silicon.Sunlight consists of little particles of energy called photons. When a PV cell is exposed to sunlight some of the photons get reflected, pass right throughor absorbed by the solar cell. When the energy of the photons is higher than the band gap energy they get absorbed by theelectrons and they move to the conduction band from the valence band.Free electrons and electron deficiencies or holes are created in the crystal lattice. When connected to an external load, electrons that are created on the n type side, may travel through the wire power the load, and continue through the wire until they reach the p-type semiconductor metal contact .The voltage measured is equal to the difference in the quasi Fermi levels of the minority charge carriers. The flow of electrons in the conduction band represents the current and so a PV cell can be modelled as a current source.

A. *Equivalent circuit of PV cell*

A PV cell can be represented by a current source, a diode, a shunt resistance R_{sh} and a series resistance R_s. The diode represents the pn junction of the cell, R_{sh} the leakage current and $R_s$the internal resistance of the cell.

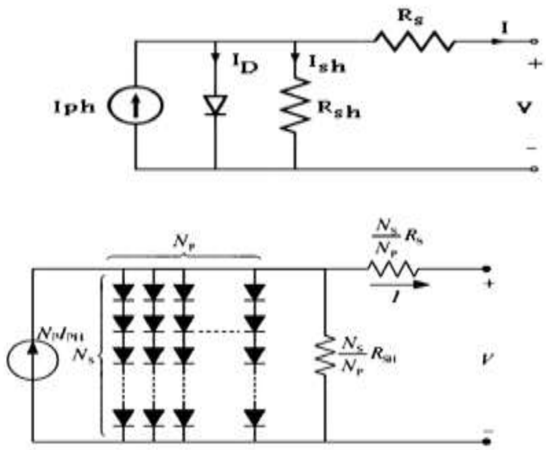

Fig. 1 Equivalent circuit of PV cell

The equation governing the output current is as follows:

$$I = I_L - I_0\{exp[\frac{q(V+IRs)}{nkT}]-1\} - \frac{V+IRs}{R_{sh}}$$

Where, q is the charge of an electron and k the Boltzmann's constant.

B. PV and IV characteristics of solar cell

The I-V and P-V characteristics of the solar cells are non- linear in nature. The solar cell characteristics mainly depend on the existing atmospheric conditions such as temperature and irradiance. Maximum power current (I_{mp}) is the amount of current of a given device at its maximum power point and Maximum powervoltage(V_{mp}) is the voltage value of a given device at its maximum power point. Maximum power point(P_{mp}) is the point where the product of current and voltage is at maximum power.

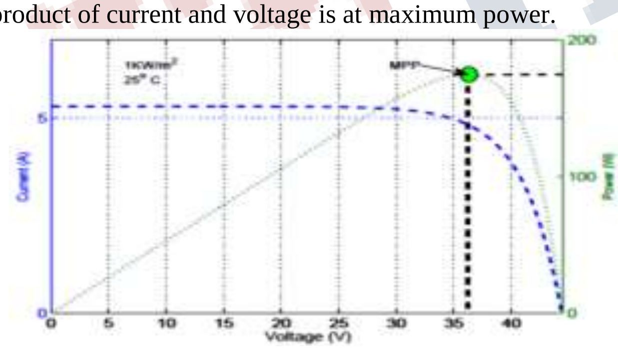

Fig .2. I-V and P-V cure of a PV cell

III. MPPT USING P&O ALGORITHM

MPPT or Maximum Powerpoint Tracking is a technique that controllers use for PV systems to maximize power output and thus the efficiency. The weather and load changes cause the operation of a PV system to vary almost all the times. A dynamic tracking technique is important to ensure maximum power is obtained from the photovoltaic arrays. The MPPT algorithm operates based on the truth that the derivative of the output power (P) with respect to the panel voltage (V) is equal to zero at the maximum power point.

There are several methods adopted for this such as the incremental conductance and the P&O algorithm.Here the maximum power point tracking using P&O algorithm is made use of. It is referred to as a 'hill climbing' method, because it depends on the rise of the curve of the power against voltage below the maximum power point, and the fall above that point. Perturb and observe is the most commonly used MPPT method due to its ease of implementation. Perturb and observe results top level efficiency, provided that a proper predictive and adaptive hill climbing strategy is adopted.

The algorithm perturbs the operating point by increasing or decreasing the voltage by a small amount and measures the PV array output power before and after the perturbation. If the power increases, the algorithm continues to perturb the system in the same direction; otherwise the system is perturbed in the opposite direction. When the stable condition is arrived the algorithm oscillates around the peak power point. In order to maintain the power variation small the perturbation size is to remain very small. The technique is advanced in such a style that it sets a reference voltage of the module corresponding to the peak voltage of the module. A controller then acts to transfer the operating point of the module to that particular voltage level.

Figure 3 shows a flowchart for reference voltage perturbation in which the PV array output voltage reference is used as the control parameter in conjunction with a controller to adjust the duty ratio of the MPPT power converter. The advantages of this technique is that it is simple to implement, the only thing needed is to measure the current and voltage from the PV cell and process this information in microcontroller.

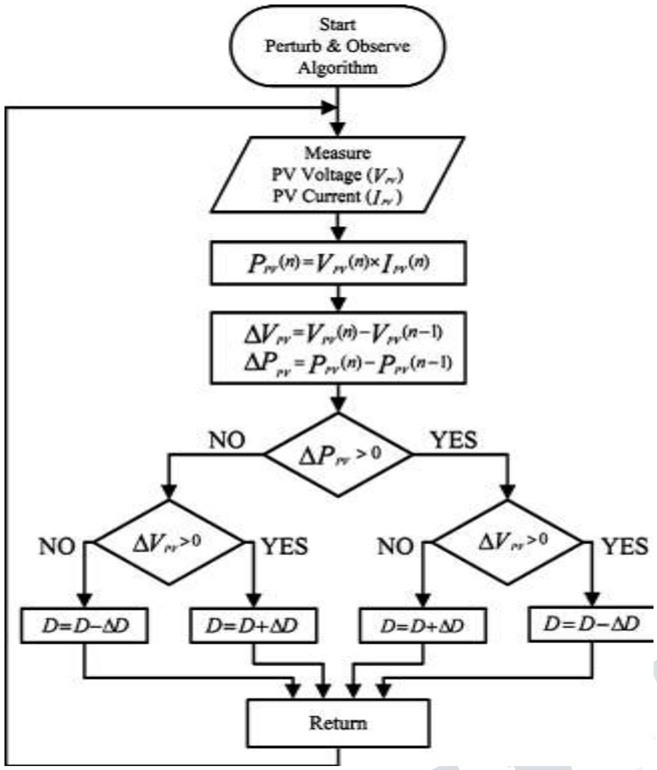

Fig. 3 Flowchart of P&O algorithm

The conventional boost converters have many disadvantages among which some can be stated as follows:

- High reverse recovery current across the rectifier diode.
- Turn on and off losses
- Leakage inductance energy(induces high voltage spikes across the active switch) and
- Current stress in switching device.

Because of the above problems an interleaved DC-DC boost converter is topology is proposed.

IV. DESIGN AND ANALYSIS OF PROPOSED IBC

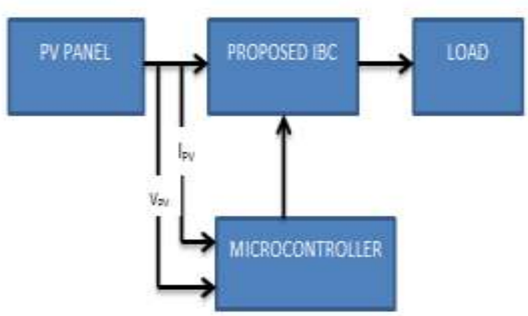

Fig.4. Block diagram of the converter

In this proposed system, the sunlight is incident on the solar panel or module, and then the voltage across the PV panel is fed into the interleaved boost converter for step up the dc voltage. The Controller is used for adjusting the duty cycle to obtain the desired output voltage.

A. Design of two phaseIBC

In high-power boost converters, the major design aspect is the selection of the boost inductor and the output capacitor. The major concern is the size, cost, and weight of such a high-power inductor that is the single heaviest component in the entire dc/dc converter. To reduce the inductor size and weight, high frequency ferrite core is used. In addition, the dc-dc converter performance directly influences the characteristics of the PV. Indeed, the ripple and harmonic content of the current is one of the various phenomena influencing PV efficiency as well as battery lifetime .So the main objective of this research is to minimize inductor size, capacitor, current/voltage ripples and harmonic content.

For reduced switching losses, proper choice of semiconductor devices, and design of inductor and capacitor, No. of interleaving units and decision on duty ratio are of importance. The methodology follows as:

- Selection of number of phases and duty ratio
- Design of inductance
- Determination of power semiconductor switches
- Designing an output filter

a) Selection of number of phases and duty ratio

It has been observed that that the ripple current in the input current decreases with increase in the number of phases. On the other hand, the cost and complexity of the circuit increases. So a compromise has made between them. In in this paper, the number of phases was chosen to be two to reduce the ripple content without increasing the cost drastically

Duty ratio also aids in ripple reduction and hence it has to be selected carefully. From the plot of the input current ripple versus the duty ratio, it can be found that for an N-phase IBC, the ripple can be zero at particular values of duty ratio. The duty cycle ratio (D) is defined as,

$$D = 1 - \frac{V_{in}}{V_o}$$

Where V_{out} is the output voltage and V_{in} is the input voltage.

b) Selection of inductors and output capacitors

Design of inductance is very important in boost topologies so that the inductor is sized correctly. The inductor value is selected using the following equation,

$$L = \frac{V_{in} * D * T_s}{\Delta I_{in}}$$

By assuming appropriate peak to peak capacitor ripple, the output capacitor value can be obtained from the following equation,

$$C_{out} = \frac{V_o * D * T_s}{R_L * \Delta V_o}$$

Where, R_L is the load resistor, D is the duty ratio and T_S is the Total time.

B. Analysis of two phase IBC

Interleaving is the process in which the pulse frequency of any periodic power source is increased.Two phase interleaving topology of a boost converter is shown in the figure 5. The main advantage of phase interleaving is that the total input current is divided into two phases,resulting in the reduction of current rating of the switching devices. The other advantages of interleaving are the reduction of the I^2R loss since the current divides into 'n' paths and also the reduction in the output ripple voltage and ripple current.

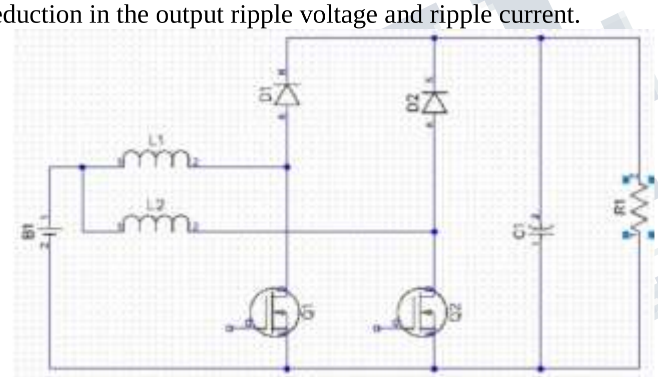

Fig.5. Circuit diagram of two phase interleaved boost converter

The operation of the converter is as follows, here similar inductors are considered i.e.; L1=L2=L.
D1 and D2 are the duty cycles of Q1 and Q2. There are three mode of operation.

MODE 1:
At t =0, the gate pulse is given to the switch'Q1' of the first phase. Then the switch 'Q1' is turned on, the current across the inductor L1 rises linearly. At the same time, the switch 'Q2' in the second phase is turned off and the energy stored in the inductor L2 is transferred to the load through the output diode D2. In this time interval, the diode D1 in the first phase is in reverse bias condition .the rate of change of il2 is given by

$$\frac{dil_2}{dt} = \frac{v_i - v_0}{L} \text{.....................(1)}$$

Whereas rate of change of il1 is;

$$\frac{dil_1}{dt} = \frac{Vi}{L} \text{..............................(2)}$$

MODE 2:
At time t1, Q1 and Q2 are opened. The inductors L1 and L2 discharge through the load. The rate of change of iLl and iL2 are

$$\frac{dil1}{dt} = \frac{dil2}{dt} = \frac{Vi - Vo}{L} \text{..........(3)}$$

MODE 3:
At t = t2, the gate pulse is given to the switch 'Q2' of the first phase. Then the switch 'Q2' is turned on, the current across the inductor L2 rises linearly. At the same time, the switch 'Q1' in the first phase is turned off and the energy stored in the inductor L1 is transferred to the load through the output diode D1. In this time interval, the diode D2 in the second phase is in reverse bias condition. At time t1, Q2 is closed. The current in the inductor L2 starts to rise while L1 continues to discharge. The rate of change of iL1 is approximately given by,

$$\frac{dil_1}{dt} = \frac{v_i - v_0}{L} \text{..............(4)}$$

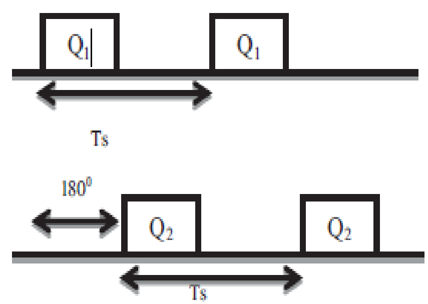

Fig. 6 Switching pattern of IBC

V. SIMULATION OF MPPT CONTROLLER WITH IBC

As per the design, the simulation of a two phase IBC with an MPPT controller was done in MATLAB. The output from the MPPT controller is given to the interleaved boost converter. The controller as mentioned before uses the P&O algorithm for maximum power point tracking. The output pulse from the controller is used to drive the IBC which consists of two parallel connected boost converter units. The MATLAB Simulink model of the proposed converter is shown in figure 7.

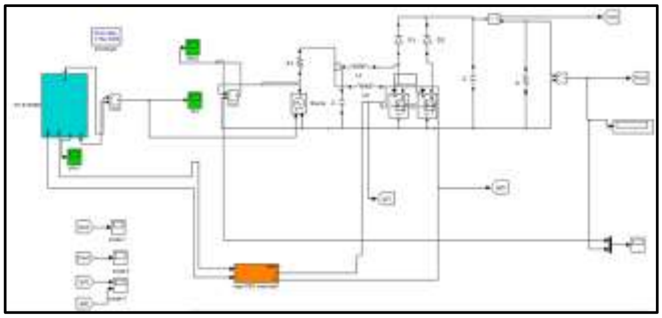

Fig. 7 MATLAB Simulink model of IBC with MPPT controller

The simulation result is as follows

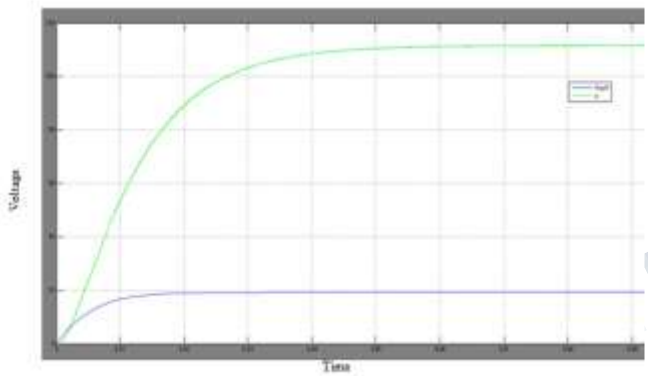

Fig.8. Input and output voltage of IBC with MPPT controller

VI. CONCLUSION

Interleaved boost converter has many advantages and is very suitable for renewable energy applications.The high efficiency interleaved dc-dc boost converter has been designed and simulated for PV applications. The disadvantages of conventional boost converters are rectified and the efficiency is improved. Here the switching losses are minimized by adopting a novel interleaving topology. The input current sharing helps in the reduction of stress on switches, which enables the introduction of low current rated switches to be used in high power density converters.In addition the output current and voltage ripples are reduced significantly. The design equations of the proposed converter are presented and performance parameters are compared using simulation. The simulation results have been presented for renewable energy applications, but the concept can be extended to higher voltage levels such as electric traction, UPS etc.

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