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Performance Analysis of Cascaded DC-DC Converter used for Distributed Generation System

Deepak[1], Ashish Thombre[2] and Arvind Sharma[3]

[1,2,3]*Department of Electrical Engineering Krishna Institute of Engineering & Technology Ghaziabad, India*
E-mail: [1]dk.ee.2001@gmail.com, [2]ashishdthombre@gmail.com, [3]arivind_652004@yahoo.co.in

Abstract—*Switching mode DC-DC Converters are critical building blocks in distributed generation system devices and hence their power efficiency, cost and accuracy are a major issues. This paper focuses on various practical aspects of cascaded structure of DC-DC converter used for boosting of voltage used for distributed generation system. Performance of the converter has been analyzed for two different conditions viz. (i) When all the distributed Voltage sources are of equal magnitude (ii) When all the distributed voltage sources are not of equal magnitude.*

1. INTRODUCTION

Increasing worldwide demand of energy is motivating people to shift their focus from conventional energy sources to non conventional energy sources. Power electronic converter is the heart of any distributed generation system. Most of the proposed approaches based on solar PV power generation system have relied on the use of series string of DC-DC converter to create high voltage string connected to the DC-AC inverter[1]. The role of boost converter is to boost up the DC voltage that it gets from the input source .Input source can be a battery bank , solar PV cell or fuel cell. In case of a solar PV cell due to partial shading conditions, the input voltage available (as a DC source) gets reduced which need the boosting up of input DC voltage. A boost converter allows boosting of DC string voltage with fewer PV panels ,while in case of buck converter more panels are required to allow the same voltage to be delivered. Buck-boost and Cuk converters are not suitable because of their poor efficiency and switch utilization. Additionally they suffers from the problem of high ripple at the output which requires a large rating capacitor and can introduce high noise problems [3].

2. STATE OF THE ART

Solar energy is one of the promising source of renewable energy, available freely worldwide. Solar PV arrays are used to harness solar energy. Due to the effect of partial shading problem of maximum power is not harnessed .It also effect the overall voltage of the system which is of great concern. Boost converter in cascaded arrangement can be used to supply the required DC power by the inverter. This is achieved by varying duty cycle irrespective of partial shading condition.

2.1 Cascaded Scheme

A cascaded or series arrangement is preferred over the parallel arrangement because in cascaded arrangement a DC to DC converter with small step up ratio (3 to 4) can be used which can ensure a good efficiency. On the other hand parallel arrangement would require higher step up ratios (more than 4) which leads to poor efficiency & higher cost due to two stage DC to DC conversion[2]. However the cascaded connection of PV panels has the demerit as it in this case, maximum power harvesting is limited by the series panel receiving minimum radiation. Parallel arrangement allows the same power to be delivered and can deliver maximum power irrespective of irradiance condition. Parallel connection requires a transformer based converter which increases the overall cost and becomes bulkier and is less efficient. In contrast to parallel arrangement of converters, series converter allows higher efficiencies close to 100% with comparatively smaller size, lighter weight and low cost and Cascaded connection allows transformer less converter operation. Cascaded connection make the use of low voltage rating MOSFETS, inductors , capacitors which reduces the overall cost of the converters. A parallel arrangement requires high voltage rating MOSFETS and other components which are comparatively costlier. A single DC to AC converter excludes the need of using per panel DC to AC inverter by which the cost of protection in control circuitry for per panel is reduced [3]. A control strategy is required to operate cascaded DC-DC converter architectures of photovoltaic (PV) modules at maximum power irrespective of the irradiance conditions, meanwhile meeting constraints of voltage-limitation type[7]

2.2 Effect Of Partial Shading

When PV panels are partially shaded there is a drop in the voltage on the series string of panels due to which the total voltage of the string may go below the minimum Voltage required by the inverter due to this the inverter may go offline & PV array would supply zero power thus output power of full array is lost due to some shaded panels while most of the panel are still getting good irradiation from the sun. A good remedy for this is to use by pass diodes so that the current from the working panels is passed through the shaded panels.

Solar photovoltaic (PV) arrays are often subjected to partial shading and rapid fluctuations of shading. So a solar PV system, capable of maximizing the power generated by every PV cell in the panel is needed[6]. Current–voltage and power–voltage characteristics of large photovoltaic (PV) arrays under partially shaded conditions are characterized by multiple steps and peaks[9].

2.3 Previous Research

Antoneta Iuliana Bratcu et al.[2] investigated the issues of ensuring global power optimization for cascaded DC–DC converter architectures of photovoltaic (PV) generators irrespective of the irradiance conditions. They proposed supervisory algorithm that attempts to establish the best suboptimal power regime.

Geoffrey R. Walker et al.[3] Stated that new residential scale photovoltaic (PV) arrays are commonly connected to the grid by a single DC–AC inverter connected to a series string of pv panels, or many small DC–AC inverters which connect one or two panels directly to the AC grid and proposed an alternative topology of non-isolated per-panel DC–DC converters connected in series to create a high voltage string connected to a simplified DC–AC inverter. They showed that buck and then boost converters to be the most efficient topologies for a given cost, with the buck best suited for long strings and the boost for short strings. While flexible in voltage ranges, buck-boost, and Cuk converters are always at an efficiency or alternatively cost disadvantage.

A cascaded DC-DC converter based on boost chopper was examined by St´ephane Vighetti et al.[4]They found that the integration of photovoltaic (PV) modules in buildings causes problems with shadows that reduce the energy produced by these systems. They proposed topologies connected to several PV and evaluated at different situations of typical shadows.

Hiren Patel et al.[5] stated that that the performance of a photovoltaic (PV) array is affected by temperature, solar insolation, shading, and array configuration. They proposed a model which conveniently interface with the models of power electronic converters. It can also be used as a tool to study the effects of shading patterns on PV panels having different configurations. They observed that, for a given number of PV modules, the array configuration significantly affects the maximum available power under partially shaded conditions.

Shih-Ming Chen et al.[8] proposed a new high step-up DC–DC converter designed especially for regulating the DC interface between various micro sources and a DC–AC inverter to electricity grid. The quadratic boost converter achieves high step-up voltage gain with appropriate duty ratio and low voltage stress on the power switch. The energy stored in the leakage inductor of the coupled inductor can be recycled to the output capacitor. [8]

3. SYSTEM DESCRIPTION

A DC- DC boost converter provides the output voltage that is always greater than the input voltage. It is basically used in regulated DC power supply. A boost converter is a DC-DC converter that supplies an output voltage that is always equal to or greater than the input voltage. It is basically used in regulated DC power supply. As shown in Fig. 2 when the switch is ON input DC voltage source supplies energy, current flows from input source V_{in} to L and switch S, During this period T_{ON} the energy is stored in the magnetic field of inductor. As the diode is reverse biased at this time so no current flows to the diode D and load .Capacitor C supplies the load current during this time. When the switch is OFF, emf is induced in inductor with reversed polarity. This induced emf in inductor is added to V_{in} Thus the voltage across L,D and C is greater than V_{in} , capacitor C is charged during this period .

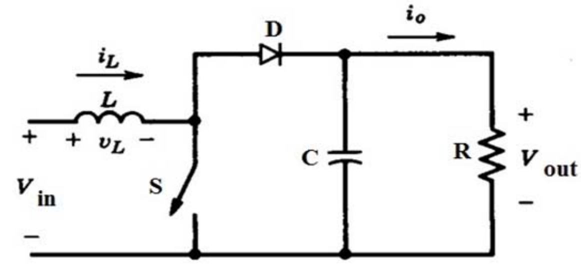

Fig. 1: Circuit diagram of Boost Converter

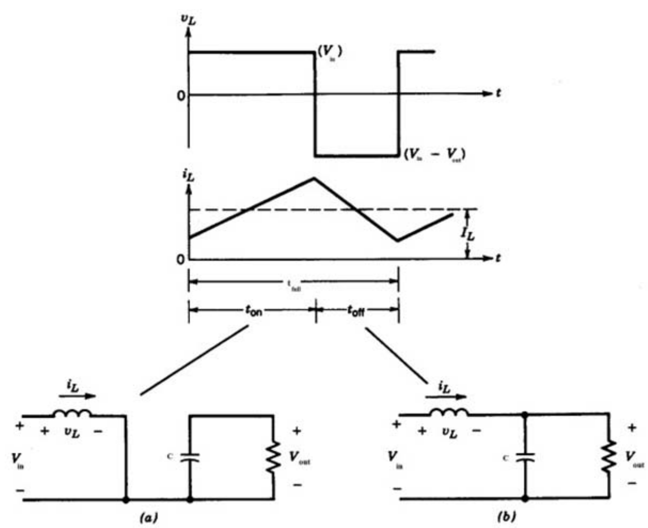

Fig. 2 (a) Switch ON mode (b) Switch Off mode

During first steady state, the time integral of the inductor voltage over one complete cycle must be zero so the equation is :

$V_{in}\, t_{on} + (V_{in} - V_{out})\, t_{off} = 0$ Now by dividing both the sides by term t_{full} and solving the terms we get.

$$\frac{V_{out}}{V_{in}} = \frac{t_{full}}{t_{off}} = \frac{1}{1-d}$$

$$V_{out} = V_{in} \frac{1}{1-d}$$

Assuming that the circuit is lossless we get.

$$P_{in} = P_{out}$$

$$V_{in}\, I_{in} = V_{out}\, I_{out}$$

$$\frac{I_{out}}{I_{in}} = (1-d)$$

Here , V_{in}=input voltage , V_{out}= output voltage, d=duty cycle ,

t_{on}= ON time of switch ,t_{off} = OFF time of switch , I_{in}= input current, I_{out}= output current , P_{in}= input Power , P_{out}= output power

4. MODELLING & SIMULATION

In this scheme, six boost converter have been cascaded in series arrangement. The input supply to each of the boost converter is fed from a battery . Each boost converter is designed by using inductor of L=13 mH and capacitor C=8000 µF , MOSFET is used as a switch. A large value capacitor is selected to minimize the ripple content in the output. The input supply to all these boost converters is DC source. By varying the duty cycle the DC voltage is regulated .This DC string voltage is further inverted with the help of a single phase voltage source inverter. Inverter is designed with the help of four IGBT switches. A LC filter smoothen the output and make it purely sinusoidal. Resistive load is connected at the output of the filter. The block diagram for the model is shown in fig.3

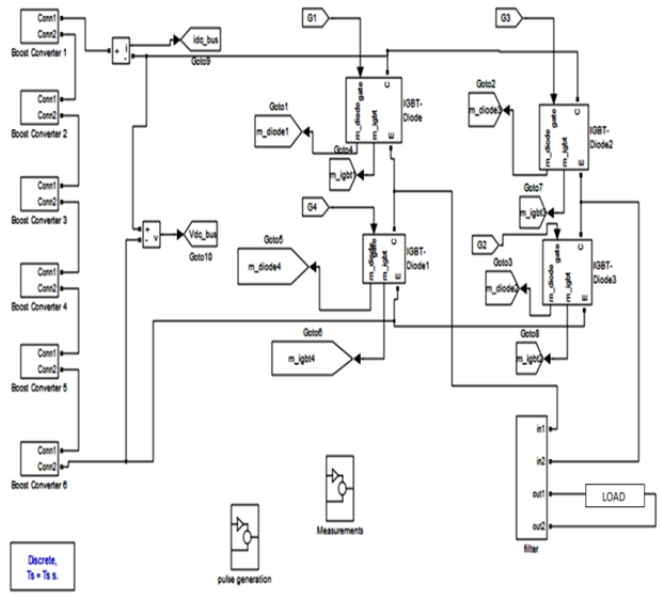

Fig. 3: Block diagram of cascaded DC-DC boost converter with VSI scheme

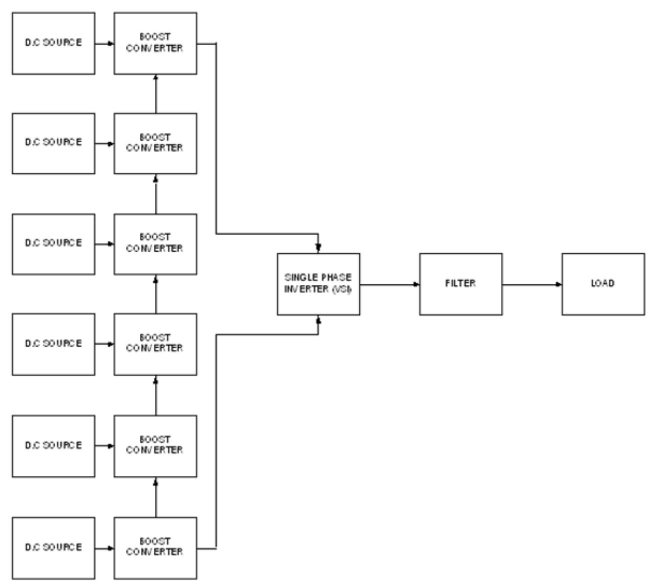

Fig. 4: The SIMULINK model of the cascaded DC-DC boost converter with VSI scheme

In this scheme two different cases have been studied:

(i) When all the DC Voltage sources are of equal magnitude (ii) when DC voltage sources are of not of equal magnitude to study the effect of drop in DC voltage due to the effect of partial shading. In this case 100 volt DC supply have been taken for the first three boost converter and 80 volt DC supply for the last three boost converters.

5. RESULTS & DISCUSSIONS

Here we have taken all the DC sources of equal magnitude, each DC source is supplying 12 V DC .

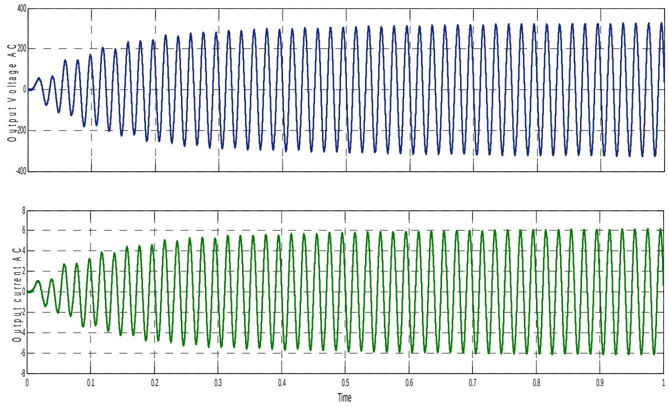

Fig. 5: Output Voltage and Current of VSI for Duty cycle 20%

Fig. 5 showing The SIMULINK results for Cascaded D.C-D.C boost converter for distributed generation systems with the above specifications for output voltage and current at duty cycle D=20%

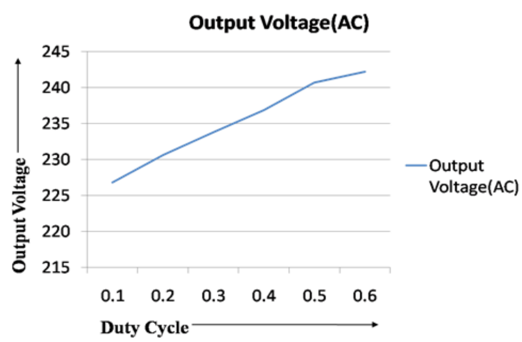

Fig: 6 Effect of Output voltage of VSI Vs Duty Cycle

It is observed that when input supply to all boost converter supplied by DC source is 12 V in that case as duty cycle is increased the output voltage and current of VSI increases progressively while On increasing the duty cycle beyond a limit the output voltage and current starts decreasing because of poor switch utilization. It is also observed that the output of VSI is sinusoidal as shown in fig. 5.

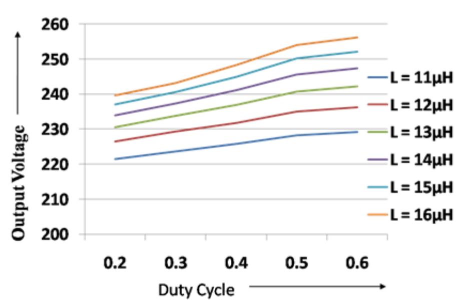

Fig. 7: Effect on Output voltage of VSI Vs Duty Cycle at different inductor values

It could be seen from fig. 7 that by increasing the value of inductor the output voltage level is increased for any given duty cycle and with the increase in value of inductor the output voltage of VSI increases. The DC input to each boost converter is taken as 12 V DC here.

Case II : Input voltage source are of unequal magnitude

To study the effect of partial shading comparative analysis of two different cases is done. In first case all DC source are of equal magnitude and supplying 100 V DC to each boost converter from B1-B6(B=Boost converter)and in second case input DC source are of unequal magnitude supplying 100 V to first three boost converters B1-B3=100 V and 80 V to last three converters from B4-B6=80V is considered for analyzing the case of partial shading. The SIMULINK results are shown in fig. 8 , fig. 9 and fig. 10.

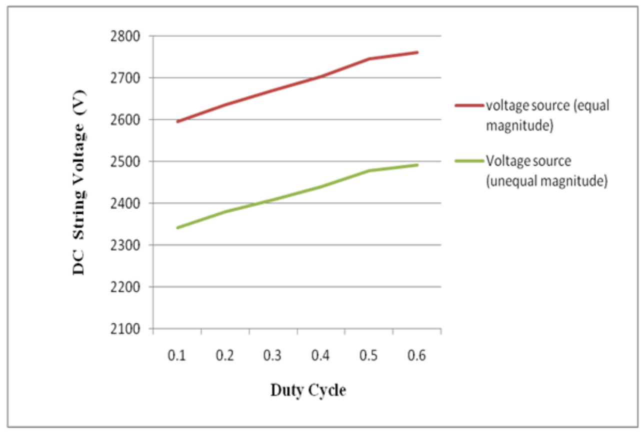

Fig. 8: Showing the variation of DC string voltage with duty cycle.

It is observed that the DC string voltage in case of when DC voltage source are of unequal magnitude of voltage, is compensated by varying the duty cycle of boost converter to maintain the value of DC voltage required by VSI. It is also observed that voltage of boost converter increases progressively by varying the duty cycle from 0.1 to 0.6. Comparative analysis of the above two cases shows that small drop in the input DC voltage causes large drop in DC string voltage.

It is observed that AC voltage and current at the output of VSI reduces in case there is drop in DC string voltage due to effect of partial shading. This drop in output AC voltage can be compensated by varying the duty cycle of the boost converter. It is also observed that by varying the duty cycle of the boost converter from 0.1 to 0.6 AC voltage and current increases progressively. Comparative analysis of AC voltage under two different cases as discussed above shows that with a small drop in DC string voltage there is a large drop in AC output voltage.

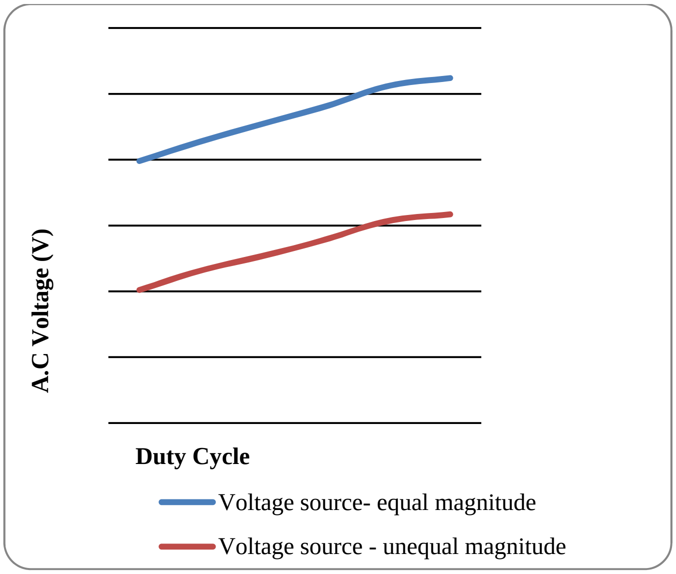

Fig. 9: Showing the variation of AC output voltage with duty cycle

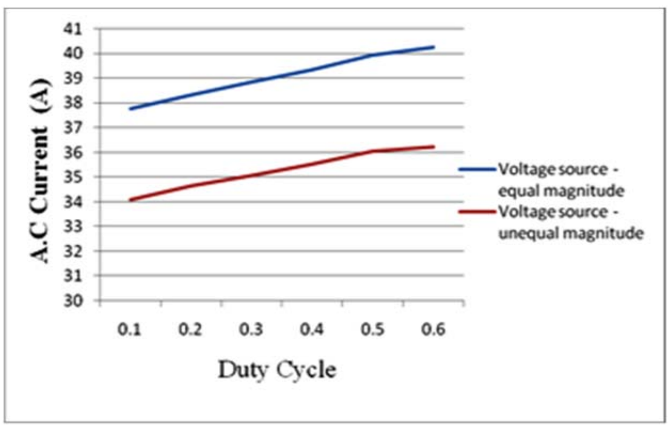

Fig. 10: Showing the variation of AC output current with duty cycle

6. CONCLUSION

This paper provided a detailed study and simulation of different aspects drop in DC voltage due to the effect of partial shading on PV cells. SIMULINK model has been developed and its results are analyzed to check its suitability and performance. It is concluded that when some of the voltage sources are not supplying the required DC voltage to the DC string due to the effect of partial shading in case of solar PV cell (the drop in DC voltage is represented by partially charged batteries), drop in the DC string voltage can be compensated to get the required value of DC string voltage by boosting up the DC Voltage of boost converter under the effect of partial shading by varying the duty cycle of boost converter. With the variation in duty cycle of boost converter DC string voltage and output AC voltage of VSI increases progressively in both the cases discussed above. It could be seen in Fig. 8 that in case of partial shading (unequal voltage) beyond a particular limit , the output DC voltage level of DC string is not achieved by merely changing the duty cycle. It need variation of inductor or addition of extra boost converter. It could be seen from Fig. 7 that by increasing the value of inductor the output voltage level is increased for any given duty cycle .

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