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HVDC Application for Different Solar PV Technology Combinations in India

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Abstract

Conventionally Grid Connected Solar PV plants initially generates DC power and then converted to AC via inverters and connected into AC grid for power transmission. Depending on the size of the plant, required environmental condition and land availability large PV plants are generally located far away from the load centre. Hence reduction of transmission loss and incised transmission capacity expansion is a greater challenge for modern newly establish solar power plant. Transmitting high voltage DC power directly from Solar PV panel to High voltage DC grid is become an accretive option for modern PV power plant. In this paper DC-DC bypass diode converter model is adopted to generate high voltage DC voltage in PV power plant. Result shows that power in the range of HVDC level can be generated when the voltage of different PV technology blocks are used as input. P-SIM software is used for simulating the circuit here.

***Keywords**: HVDC, PV panel, DC-DC converter, P-SIM*

1. Introduction

Traditionally due to economic growth the demand for electricity has been increasing in India [1, 2]. There are many instantaneous bad effects on the environment such as large amount of greenhouse gases (GHG) and pollutants emissions from the burning of fossil fuels [3]. The efficiency of the electricity production sector may be improved, and there is potential for a shift from coal to other fuels, such as renewable energy [4-8]. Impact of renewable energy on the electricity market in India was discussed by Chattopadhyay [9]. Due to strong climate concerns large photovoltaic (PV) generation plants are rapidly spreading all over the industrialized countries [10-12]. Solar energy has a key role for the achievement of Indian energy targets to be accomplished in the near future. Installation of Solar power plants represents one of the solutions to ensure an increasing participation of solar power in the energy mix of the country. Many large scale solar power plants have been built in locations which are far away from the load centre depending on the size of the plant and land availability.

In many developing countries, electricity theft and line losses are a costly burden on the power sector [13]. In India, average T & D (Transmission & Distribution) losses; have been officially indicated as 23 percent of the electricity generated. However, as per sample studies carried out by independent agencies including TERI, these losses have been estimated to be as high as 50 percent in some states [14]. Carolien et al. concluded that reducing electricity losses during transmission and distribution would reduce emissions by 6% and electrical efficiency of power plants improves by 9% in India [15]. Transmission and distribution (T&D) losses are estimated to cost India's economy 1.5% of GDP each year, aggravating chronic power shortages and straining the precarious finances of its public electricity providers [16].

High voltage direct current (HVDC) is used for long transmission to reduce transmission losses. HVDC is technically and economically attractive to deliver the power produced by these solar power plants to the grid when distances are particularly large. Humpert analyzed the state of the art of long distance UHVDC transmission systems and the possible future development [17]. HVDC becomes especially interesting for linking geographically distanced renewable energy power plants through a multi-terminal grid [18]. To transmit bulk power over larger distances of several thousand km via overhead lines, Ultra-High-Voltage DC (UHVDC) transmission with DC-voltages of 800 kV is the preferred solution. Vindhyachal Back-To-Back

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HVDC link connects Northern and Western regions with 2 lines. Vindhyachal HVDC line operates at a DC voltage of 70 kV and has a transmission power of 250MW.1825 km long Biswanath Chariyali – Agra HVDC transmission line connects Assam to Uttar Pradesh. Its maximum power transmission capacity is 6000 MW and the transmission Voltage is 800 kV [19]. In India, there have been many inter-regional transmission projects, again involving long distance HVDC lines. Among the many projects, one of the world's longest HVDC transmission line is in operation in India, bringing about 2000 MW from the Eastern grid to the South through the 1400 km HVDC line from Talcher in Orissa to Kolar in Karnataka via two states, Andhra Pradesh and Tamil Nadu. High efficiency Step-Up HVDC converter for photovoltaic generator is proposed in some literatures [20-23].

In a traditional PV plant a large number of PV modules are series connected in long strings and a single centralized inverter provides the voltage inversion. Such a string architecture is burdened by a low efficiency. More sophisticated architectures have been developed where PV modules are arranged in strings, or even substrings, each one connected to the grid through a dedicated inverter, or a dedicated DC/DC converter and a centralized inverter [24, 25]. In [26] a method is introduced to reduce the output current ripple of the converter and presented a detailed analysis of the output current ripple of the DC-DC boost converter to provide a guideline for the design of the battery charger. In [27] investigated and compared conventional dc-dc converter and diode assisted dc-dc converter in wide range power conversion from the aspects of silicon devices. Grid-connected PV system can eliminate the need for batteries and associated accessories [28]. An important number of step-up structures using active switching components were proposed for photovoltaic systems with converters associated to individual or to a set of parallel, series or mixed associated photovoltaic panels.

In this paper a new concept of connecting panels of different technologies with same current rating is introduced. In this new concept panel voltage is directly converted to HVDC level to transmit a long distance.

2. HVDC and Solar PV

HVDC first became a feasible transmission technology in the 1950s. Today, the highest-capacity projects have capacities between 3000 and 6400 MW at the voltage levels of ±500, ±600, and ±800 kV [29]. There are many nation-wide and inter-regional transmission projects conceived in India and China using HVDC/ UHVDC in conjunction with FACTS devices [30]. Future HVDC appears likely at ±600 and ±800 kV [31], and some consideration has been given to the use of ±1000 kV. HVDC is well-known to be an attractive option for bulk power transmission in below mentioned applications: (1) Interconnecting two asynchronous networks. (2) When the uninterrupted transmission distance exceeds about 600 km, either to move energy from a specific generation facility to a specific load centre or to interconnect two areas of a single network. (3) For underground transmission. It may be particularly effective, in terms of economic benefit and in terms of transmission system performance, to interconnect asynchronous networks with long-distance.

Different PV technologies are discussed in many literatures [32, 33] and it is well established that different technologies has different current and voltage rating depending on their power rating. Connecting different PV technology blocks using HVDC concept is a new one which can reduce the transmission and distribution losses in case of long distance power transmission [20-23]. DC-DC Boost converter concept is used here for increasing the panel voltage up to the HVDC level.

Schematic of proposed concept is shown in Figure 1. In this concept different PV technology blocks with same current rating but different voltage can be connected together. So PV panels of different technologies can be used in same PV power plant if current rating of the blocks remains same using proper combination of panels. Bypass diode is used to protect from lower current generation from a particular block due to meteorological parameter variation or any fault. The output of the boost chopper can achieve as high as HVDC level as high input voltage can be introduced using this concept.

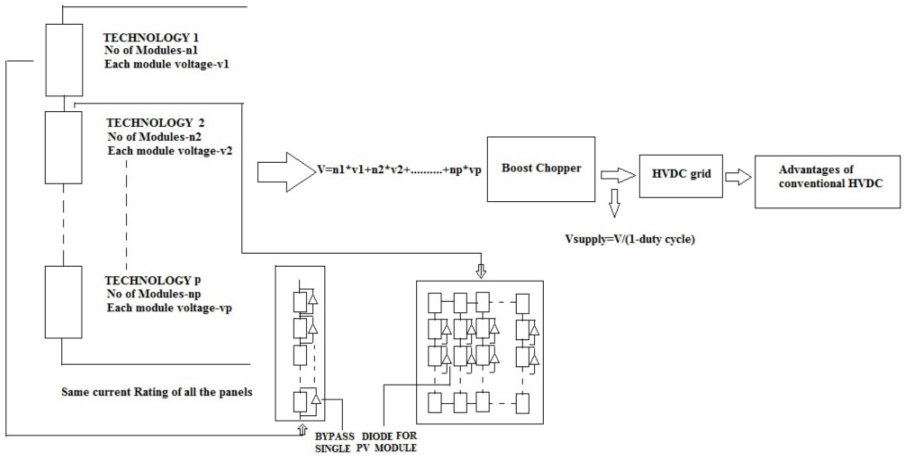

Figure 1. Proposed schematic for different PV technologies connected to HVDC grid

3. Boost Converter and Its Operation

DC-DC boost converter concept is used in this paper for HVDC application of Solar PV plants.

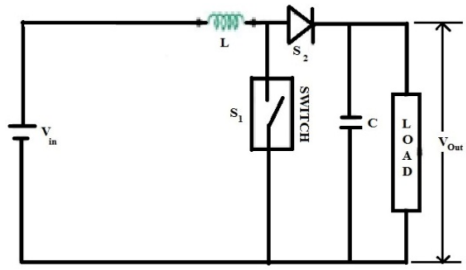

Figure 2. Circuit diagram of a Boost Converter

3.1. Mode-I Operation Of Boost Converter

In mode-I switch S_1 is closed the inductor gets charged through the battery and stores the energy. In this mode inductor current rises (exponentially). The diode (S_2) blocks the current flowing and so the load current remains constant which is being supplied due to the discharging of the capacitor C.

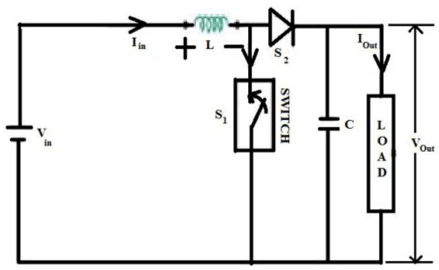

Figure 3. Mode-1 operation of a Boost Converter

3.2. Mode-II Operation Of Boost Converter

In mode-II the switch S_1 is open and so the diode (S_2) becomes short circuited. The energy stored in the inductor, L gets discharged through opposite polarities which charge the capacitor, C. The load current remains constant throughout the operation.

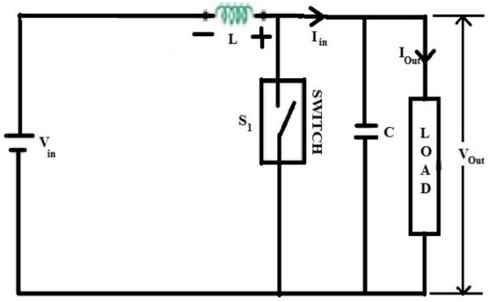

Figure 4. Mode-2 operation of a Boost Converter

$$S_1 + S_2 = 1 \quad (1)$$

$$V_{in}(t) = S_2\, V_{out} = (1 - S_1)V_{out} \quad (2)$$

$$I_{out}(t) = S_2\, I_{in} = (1 - S_1)I_{in} \quad (3)$$

$$< V_{in} >= D_2\, V_{out} = (1 - D_1)V_{out} \quad (4)$$

$$< I_{out} >= D_2\, I_{in} = (1 - D_1)I_{in} \quad (5)$$

Let,

$V_{in} =< V_{in} >$ and $I_{out} =< I_{out} >$

$$V_{out} = \frac{1}{(1-D_1)}\, V_{in} \quad (6)$$

$$I_{in} = \frac{1}{(1-D_1)}\, I_{out} \quad (7)$$

The input and output power must be always equal. There are no places for energy to be lost in this converter. Switch-1, S_1 carries I_{in} when on. When S_1 is off, switch-2, S_2 must be on and switch-1 must block V_{out}. Therefore S_1 must be a forward–conducting, forward –blocking device. Switch-2 can be a diode.

4. Simulation and Results

In this present work, functional solar PV panel connected with DC-DC boost chopper is simulated using P-SIM software. Mathematical calculation for selecting the value of inductor and capacitor is done using conventional method. Functional solar PV panels have four input parameters, open circuit voltage, short circuit current, maximum power point voltage and maximum power point current. Functional Solar PV panel of 21V and 45V open circuit is simulated to see the output voltage at the load end. The circuit configuration and waveforms in P-SIM are shown below.

21V solar PV panel is connected with the designed boost converter as shown in Figure 6 and simulated. Simulation result with output voltage of 190V shown in Figure 5 and Figure 7. In Figure 6 simulation results up to 0.006 seconds is shown to visualize the transients in output voltage and from Figure 7 it is very clear that the output voltage becomes stable with in .01 Sec. Another solar PV panel of 45V is also simulated and its output voltage is shown in Figure 8. 45V panel voltage is boosted up to 240V.

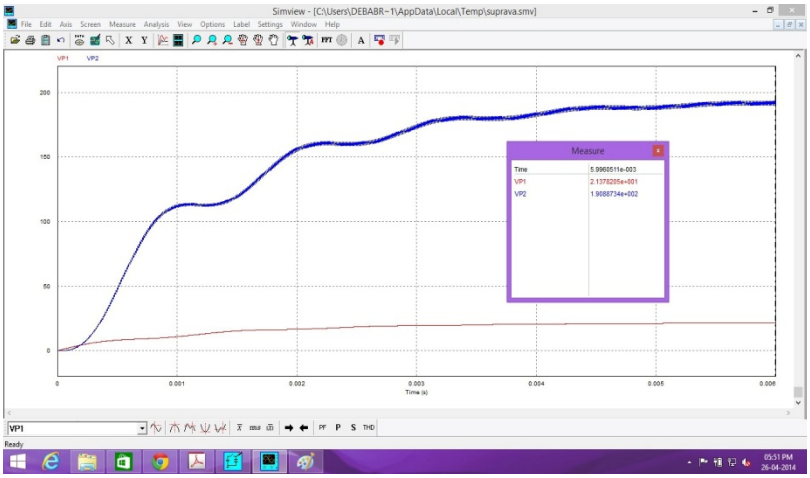

Figure 5. P-SIM Simulation model with Solar 21V PV panel for 0.006 sec

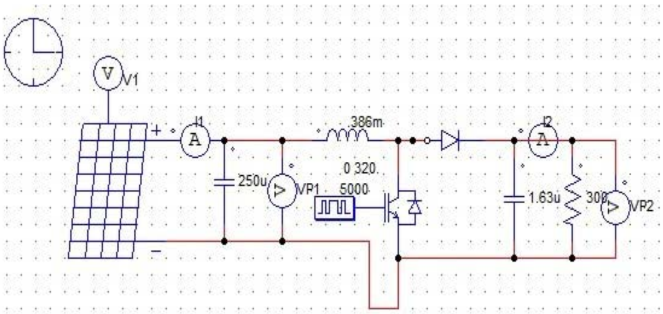

Figure 6. P-SIM Simulation model with Solar PV Panel

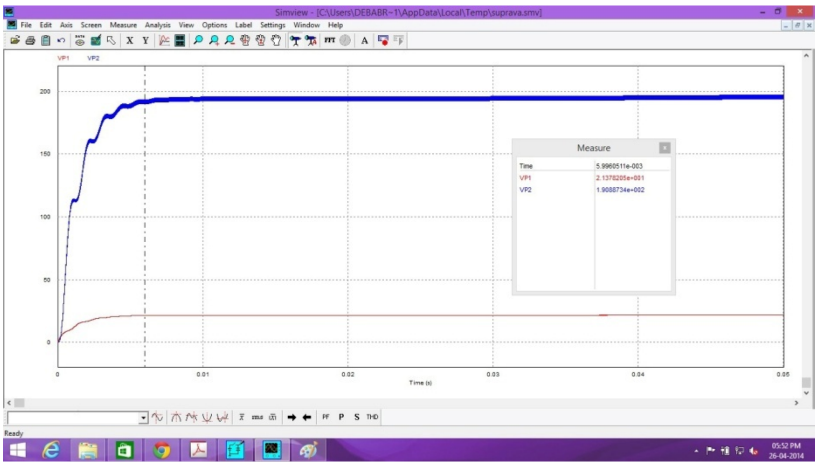

Figure 7. P-SIM Simulation model with Solar 21V PV panel for 0.05 sec

In Figure 8 the simulation result is shown up to 0.025 sec. In this figure transient is very clear and it is also seen that with in very few mili seconds the output voltage becomes stabilized.

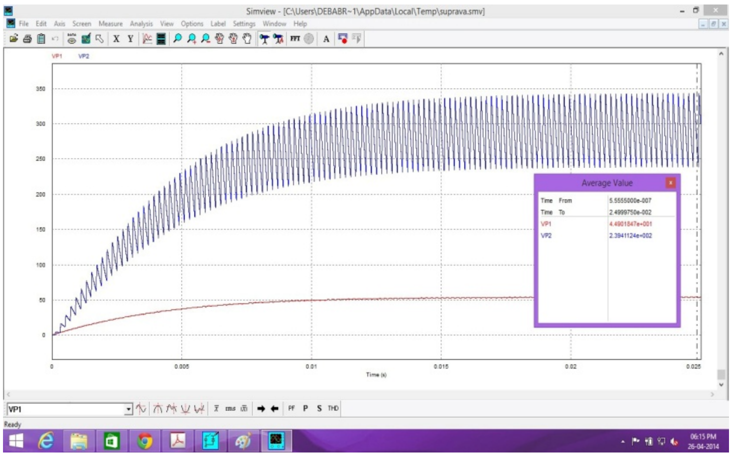

Figure 8. P-SIM Simulation model with Solar 45V PV panel for 0.025 sec

5. Conclusion

This paper has analyzed the boosted output power from Solar PV panels using P-SIM software. The following points summarize the work presented in this paper.

1) Using P-SIM software it is seen that output voltage as high as nine times the PV input voltage can be achieved.
2) Output voltage stabilizes within very small duration of time in the range of mili seconds.
3) Solar PV panels of different technologies with same current rating but different voltage can be connected in this HVDC scheme.
4) All the advantages of using HVDC will be added with advantages of using solar PV.
5) Bypass diode concept is also introduced to eliminate the reduction in power generation due to fault in certain type of PV block.

In this paper only simulation results are shown which concludes high power output can be achieved from the solar PV panels using the proposed scheme which can be used for HVDC when more number of panels is connected in series to generate the input voltage. This work presents a preliminary study of the concept. This study is planned to extend for real time simulation with different PV panels of same current rating but different voltage rating to see the practical viability of the concept.

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