Design Hybrid Transformer based on Multi-Stage High Boost Ratio DC-DC Converter for PV Grid Applications

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Abstract - *Integrating the power from the photovoltaic (PV) module into the existing power distribution infrastructure is achieved using power conditioning systems (PCS). The DC–DC conversion stage of the PCS requires a high efficient and high boost ratio DC–DC converter to increase the low DC input voltage from the PV panel to a higher DC voltage. In this work proposes a high boost ratio hybrid transformer DC to DC converter and a full- bridge inverter to convert DC-AC, as the grid voltage is AC in nature. Total Harmonic Distortion is generated by inverter which is minimized by using a low pass filter so that the system is within its acceptable limits. A feedback loop is used in the boost converter to control the converter output voltage. Phase control circuit is required to maintain a constant output voltage at the load side since the PV system output voltage varies continuously in nature.*

Key Words: Hybrid transformer, High boost ratio DC-DC converter IGBT, Full-Bridge Voltage Source Inverter, PV array.

1. INTRODUCTION

With increasing concern about non-renewable sources of energy, the steady increase in fossil fuel prices, global warming, environmental degradation and the ecosystem. Renewable energy is becoming increasingly popular and attracting more attention as an alternative to non-renewable energy sources. Among the renewable sources of energy, energy is considered to be the most important, most reliable and most sustainable energy source compared to other types of energy sources such as wind, tides, etc., by photovoltaic effects.

Solar energy is a kind of energy derived from the sun in the form of solar radiation and its converts into electricity. When the PV system is connected to grid is called Grid Connected PV System, it become more popular because of their applications in distributed generation and for more effectively using the PV array power.

2. SYSTEM DESCRIPTION

Fig.1 shows the components of the grid-coupled photovoltaic system with two stages for process automation and feed into the grid. The system consists mainly of a matrix of PV arrays that convert sunlight into direct current, a DC / DC boost converter to increase the PV array voltage to a higher level DC voltage and an inverter that is capable of converting the PV array voltage to a higher level DC power to alternating current. The generated alternating current supply is fed into the grid and / or is used by the local loads.

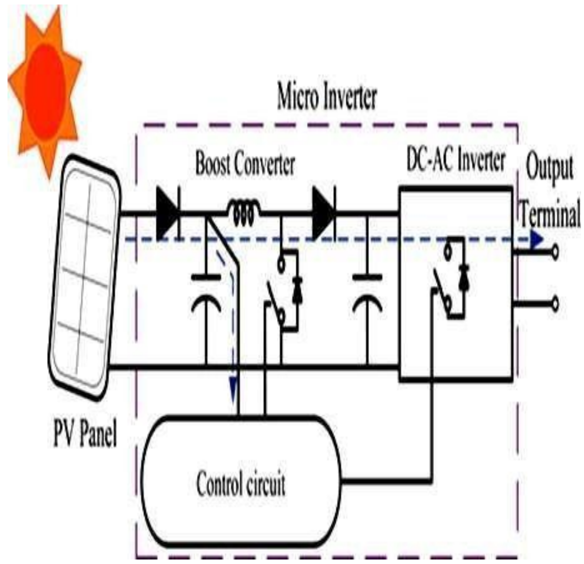

Fig -1: Components of Grid connected PV systems.

3. OPERATING MECHANISM OF PROPOSED MODEL

A. High boost ratio DC to DC Converter

Current study shows that it is a combination of flyback and boost converters. Flyback converter consists of L1=L2, Cr, Dr & Lr and a boost converter, which consists of L1, S1, D1 & Cc. Hence the flyback output is nD/ (1- D) and boost output is 1/(1-D), the total output voltage is(1 +nD)/1- D).

(1) Boost Converter and its working

DC to DC Converters are used for converting one level of DC voltage (usually unregulated) to another level of DC voltage (regulated). This transformation is done with the help of a network consisting of storage elements like inductor and capacitor.

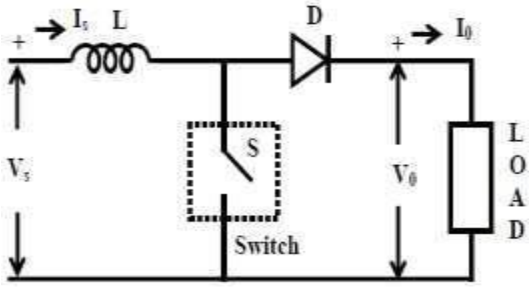

Fig. 2- Boost converter.

The boost converter is the tendency of an inductor to oppose sudden changes in current. In a boost converter, the output voltage is always higher than the input voltage. A schematic of a boost converter is shown in Fig. 2. Here, IGBT is used as a switch. When the switch is turn-on, the current flows through the inductor (L) and hence energy is well as magnetic flux increases and storing energy in the transformer. The voltage induced in the secondary winding is negative.

(ii) Flyback Converter

It is suitable for both AC to DC and DC to DC conversion with galvanic isolation between the input and outputs. This is a type of buck-boost converter with the inductor split to form a transformer. Hence the voltage ratios are multiplied with an additional advantage of isolation.

The working principle of Fly back converter, when the switch is turned-ON, Transformer primary is directly connected to the input voltage source. So primary current as well as magnetic flux increases and storing energy in the transformer. The voltage induced in the secondary winding is negative.

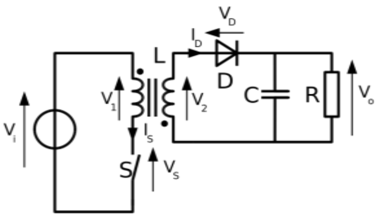

Fig. 3- Flyback converter

So the diode is reverse-biased i.e. blocked. The output capacitor supplies energy to the load. When the switch is turned-OFF, the primary current and magnetic flux drops, Then the secondary voltage is positive i.e. forward-biasing the diode, allowing current to flow from the transformer. The energy from the transformer charges the capacitor And supplies the load.

B. Control of DC to DC converter

The output voltage of DC to DC converter is controlled or regulated by switching ON and OFF the switch, in a periodic manner. The regulation is normally achieved by Pulse Width Modulation (PWM) technique at a fixed frequency.

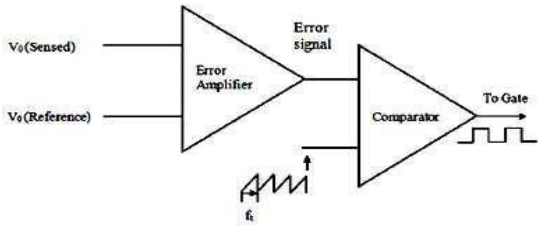

Fig. 4- Control circuit

Where T is the time period of switching device and it is nothing but the addition of ON and OFF time of a switching device which is given by
T=TON+TOFF

As the ratio TON/T is duty ratio and as this duty ratio varies, the output voltage also varies. This is called constant frequency, variable duty ratio control.

Control circuit of boost converter is for regulation purpose, output voltage is continuously sensed Vo (sensed) and compared with a reference voltage Vo (reference).The resulting error signal is compared with a sawtooth waveform having frequency ft. The output of a comparator is fed to the switch or fed into the gate of a power IGBT . Usually, frequency in kilohertz is selected so as to maximize the efficiency of a converter.

C. Drawbacks in current DC to DC converter

As per the present scenario, utilization of renewable energy sources such as PV modules need power conditioning systems (PCS) to improve the stable output. Current study shows it is not that much effective to boost the power to meet the requirements in peak load duration. To overcome these limitations, we need a high efficient and high boost ratio dc–dc converter to increase the low dc input voltage from the PV panel to a higher dc voltage.

I. PROPOSED CONVERTER AND ITS DESIGN CONSIDERATION

Here, in previous study, DC to DC convertors have many limitations over the output and comparative gain is also low. In order to be used in higher power level conversion applications, the interleaving method is proposed in this paper which not only improve the gain but also it can be used for high power application as in PV Grid.

During the switch S1 off period, Secondary reflected voltage of the transformer is equal to nVin.

Therefore Vcc can be given as

$$V_{cc} = V_{in} + \frac{DV_{in}}{1-D} \quad ...1$$

$$V_{cc} = V_{in}\left[1 + \frac{D}{1-D}\right] = \frac{V_{in}}{1-D} \quad ...\ 2$$

During the switch S1 ON period with Vcc constant, Vcr can be given as

$$V_{cr} = V_{cc} + nV_{in} \quad ...3$$

$$V_{cr} = \frac{V_{in}}{1-D} + nV_{in} = V_{in}[\frac{1}{1-D} + n] \quad ..4$$

After calculating voltage across the clamp capacitor and resonant capacitor, we can now calculate the output voltage Vo.

$$V_o = V_{cc} + V_{cr} + \frac{nV_{in}D}{1-D} \quad .....5$$

$$V_o = V_{in}[\frac{1}{1-D} + \frac{1}{1-D} + n + \frac{nD}{1-D}] \quad ....6$$

Boost converter output = Vin

$$V_o = V_{in}[\frac{2}{1-D} + + \frac{n-nD+nD}{1-D}]$$

II. MODELING AND SIMULATION RESULTS

Modeling of High Boost ratio DC-DC Converter

Fig. 7 shows the model of a boost converter developed in MATLAB/Simulink. This is the model developed from high boost ratio converter using the parameters given in Table. In this model R represents the load resistance whose value is 10 Ω.

Parameter	V_{in} (V)	R_{in} (Ω)	C_{in} (μF)	C_r (μF)	L_r (μH)	C_c (μF)	C_o (μF)	V_o (V)
Single Stage Convertor	40	10	5	0.5	2.2	20	2	410
Two Stage Convertor	40	10	5	0.5	2.2	20	2	740

SIMULATION

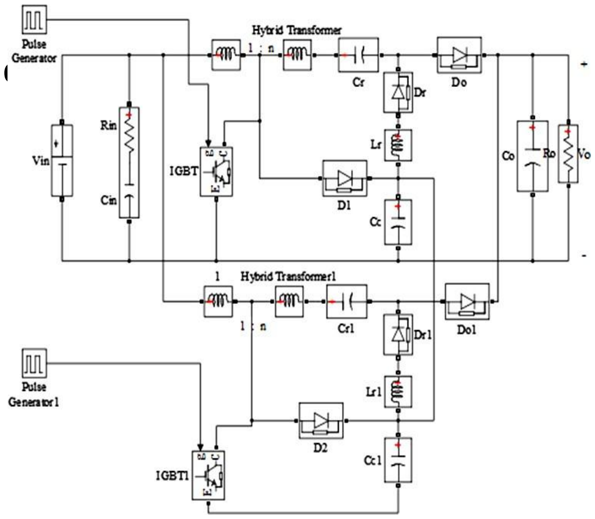

Fig. 5. Model of High Boost ratio DC-DC Converter

Fig. 5 represents Simulink model of proposed two stage high boost ratio hybrid transformer dc to dc converter. In this input voltage = 40 V given to this converter. The voltage is stepped up using a hybrid transformer and due to the capacitance Co the ripples will be reduced and the fine DC voltage is obtained at the output side of the circuit.

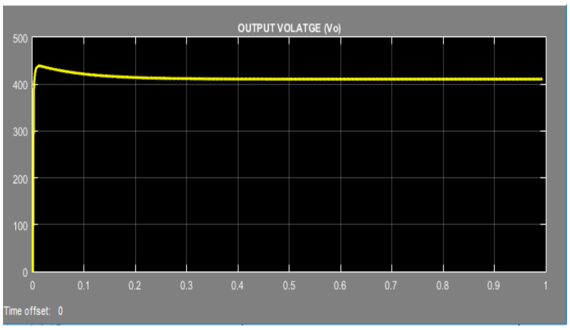

Fig.6. Output voltage of Single Stage Convertor at input voltage = 40V

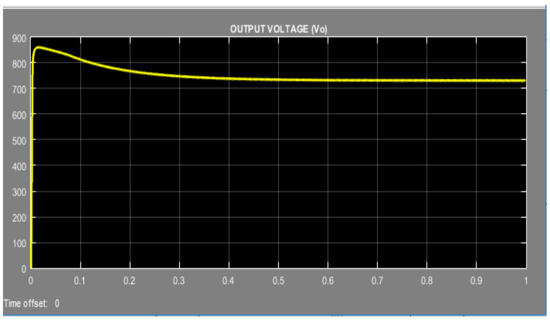

Fig.7. Output voltage of two Stage Convertor at input voltage = 40V

Comparing above to two result (i.e. Fig. 6 & Fig. 7) which clearly shows the output voltage waveform of single stage which is seen that the voltage gradually increasing from 0V to 410V and proposed high boost ratio hybrid transformer DC-DC converter with two stage which is seen that the voltage gradually increasing from 0V to 740V, we conclude that the two stage convertor is best suitable.

4. CONCLUSIONS

This proposed work boosted output voltages with low DC input voltage have following advantages over the previous works and having following features and benefits:-

1) The main feature of this converter, transfers the capacitive and inductive energy simultaneously to increase the total power delivery to the load by reducing losses in the system.
2) From simulation results it is clear that, the conversion ratio is approximately 10, with the output voltage 410V for single stage along with IGBT used as a switching device.
3) Proposed two phase extension of DC to DC converter, the conversion ratio is approximately 19 times, with output voltage nearly 740V.
Hence, with these improved performance, the converter can maintain high efficiency under low power and low input voltage condition.

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