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Simulation of a Buck-Boost Single Phase Voltage Source Inverter for Distribution Generation Systems

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Abstract: *Inverters of PV system based distributed generators (DG), are often subjected to wide changes in the inverter input voltage, which is either above or below the output ac voltage, thus demanding a buck-boost operation of inverters. Many traditional full-bridge inverters and single-stage buck-boost inverters either have complex structure or have limited range of input dc voltage. In this paper, a` single-phase transformer less inverter topology is implemented that can operate over a wide dc input voltage range making it suitable for distributed generation applications. This topology of the inverter has multiple stages and uses six switches. Depending on the reference value set, the inverter output voltage can be either boosted or bucked with respect input voltage. Simulations were carried out using MATLAB simulink software package and results show that the proposed topology boosts or bucks the output voltage level depending upon the value of the reference signal. The necessary capacitor and inductor are easier to design than those for filtering the output of traditional inverters.*

Keywords*-Buck-Boost inverter,Distribution generators, Full bridge inverter, multiple stages, refence signal***.**

I. Introduction

Distributed generation (DG) systems are usually small modular devices close to electricity consumers. These include wind turbines, solar energy systems, fuel cells, micro gas turbines, and small hydro systems, as well as relevant control and energy storage systems. Such systems normally need inverters as interfaces between their single phase loads and sources as shown in Figure 1.1, which depicts a renewable energy based DG system[1]-[5]. DG inverters often experience a wide range of input voltage variations due to the fluctuations of energy sources, which impose stringent requirements for inverter topologies and controls.

Functions of inverters for small DG systems can be summarized as follows.

- Power conversion from variable *dc* voltage into fixed *ac* voltage for stand-alone applications or *ac* output in synchronism with the grid voltage and frequency for grid-connected applications. The variable *dc* voltage can be higher or lower than the *ac* voltage in a system, which is observed normally in a wind-turbine and solar energy systems. Thus, there is a need to buck or boost the inverter voltage, as the case may be.
- Output of inverter gives power quality assurance with low total harmonic distortion (THD), voltage and frequency deviation, and flickering.
- Protection of DG generators and electric power systems from abnormal voltage, current, frequency and temperature conditions, with additional functions such as anti islanding protection and electrical isolation if necessary.

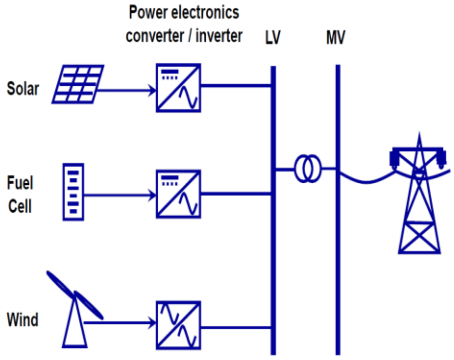

Fig 1: Renewable energy based distribution generation system.

Based on the electrical isolation between the input and output, Inverters can be classified as isolated or non isolated. Electrical isolation is normally achieved using either line-frequency or high-frequency transformers [1].

The *dc*-link voltage of inverters for DG systems may vary over a wide range. Depending on the input *dc* voltage range in comparison to the output *ac* voltage, inverters can be buck inverters, boost inverters, or buck-boost inverters. Different *dc* voltages are applied to the inverter input because of the new energy sources, such as solar batteries and fuel cells, which produce different *dc*-voltage levels [4]. Generally, most topologies are boost or buck–boost due to two main factors. First, pulse width modulation (PWM) produces an output voltage lower than the *dc* link voltage therefore, the *dc* link should be greater than the maximum possible *ac* output voltage. Second, sometimes, independent of frequency, voltage step-up is necessary [3].

Traditional full-bridge inverters do not have the flexibility of handling a wide range of *dc* input voltages. Especially when the *dc* voltage is lower than the *ac* voltage, heavy line-frequency step-up transformers are required. Although these inverters demonstrate robust performance and high reliability, they demand higher volume, weight and cost for DG system applications [2], [4].

Buck-boost inverters have the advantage of converting *dc* voltage higher or lower than the utility voltage without utilizing a line frequency transformer. Two stage or multiple stage configurations are commonly used in buck-boost inverters. Such inverter systems have *dc-dc* or *dc-ac-dc* converters added to obtain an elevated *dc* voltage ahead of inversion. A two-stage buck-boost inverter can achieve a relatively high power capacity; nevertheless, the additional power stage requires more power components and thus higher costs [4].

II. Block Diagram of Buck-Boost Single Phase Voltage Source Inverter For Distribution Generation

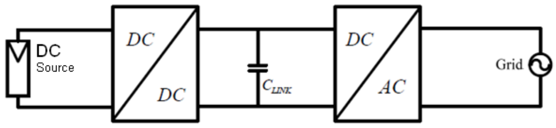

Fig .2: General Block diagram of buck-boost single phase voltage source inverter for distribution generation

Block diagram of buck-boost inverter single phase voltage source inverter for distribution generation is shown in Fig.2. From block diagram it can be seen that voltage supplied from energy source (Photo voltaic, wind turbines, fuel cell) goes through two stages of conversion before it is supplied to grid. The voltage from the energy source (*dc*) is first converted into variable *dc* using a *dc*-*dc* converter. This variable *dc* voltage is then converted to *ac* voltage and is given to grid. The capacitor link acts as a voltage source to the inverter

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III. Proposed *dc* to *ac* converter

The block diagram of multiple stage buck-boost inverter used for the proposed system is shown in Fig 3. Dc voltage obtained from the photo voltaic cells is given as input to *dc*- *dc* converter. Depending upon the reference value set, *dc*-*dc* converter either boosts or bucks the input voltage to 325V*dc*. Dc voltage is converted to *ac* voltage by switching the switches of two arms of H-bridge complementarily. The obtained 230V, 50Hz, *ac* voltage is fed to grid.

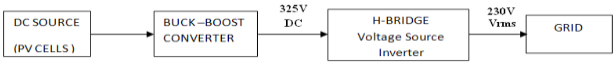

Fig 3: Block diagram of buck-boost voltage source inverter.

The *dc* link voltage is produced by buck–boost converter, prior to being converted to *ac* by the low frequency output H-bridge. A sine reference gives a sinusoidal voltage output that can be used in applications, such as drives, distributed generation, and power systems. Fig 4 gives the schematic of proposed inverter circuit.

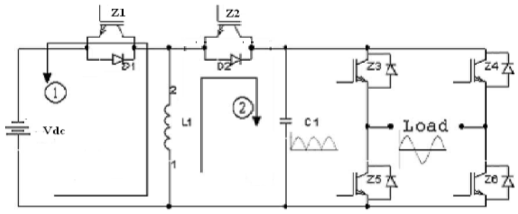

Fig 4: Proposed *dc* to *ac* converter schematic

3.1. Working principle.

For unidirectional operation of the proposed topology of the inverter Z_2 is kept turned OFF throughout the operation. It can be used for bidirectional operation. Switches Z_1 and four switches of H-bridge Z_3, Z_4,Z_5,Z_6,turned ON and OFF. Average output voltage of buck-boost converter across the capacitor depends upon the duty cycle D. Equivalent circuit for unidirectional buck-boost operation of the converter is shown in Fig 5.

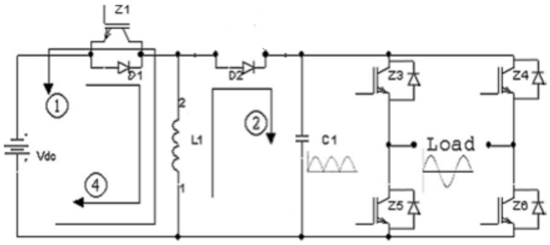

Fig 5: Equivalent circuit for unidirectional buck-boost operation of converter with H-bridge inverter.

When switch Z_1 is ON, input voltage provides energy to inductor and the diode is reversed biased. When switch Z_1 is turned OFF, the energy stored in the inductor is transferred to the capacitor $C_{1.}$ The regulated *dc* voltage across the Capacitor C_1 acts as the *dc* link voltage to H-bridge inverter. By switching switches Z_3, Z_6 and Z_4,Z_5 of H-bridge complementally at power frequency ac voltage can be obtained. This voltage can be supplied to grid.

3.2 Flow chart and design consideration for the simulation.

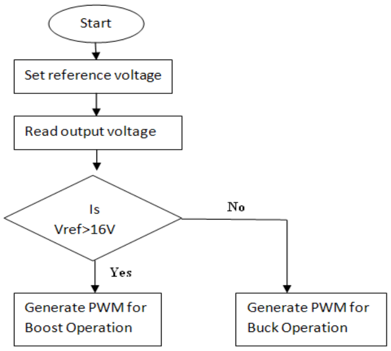

Fig 6: Flow chart to generate PWM for switches Z_1

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Flow chart to generate PWM for the switch Z_1 is shown in Fig 6. From flow chart it can seen that the nominal value of reference sine wave amplitude is 16V. If the reference sine wave amplitude is greater than 16V, the proposed inverter topology acts as a boost inverter whereas if it is less than 16V it acts as a buck inverter. However for if reference sine wave amplitude is equal to 16V, then the proposed topology of the inverter neither boosts the input voltage nor bucks the input voltage, it converts the *dc* input voltage to corresponding output *ac* voltage at 50Hz.

Since the inductor current is discontinuous, the maximum Period for L_1 to deliver energy from or to the *dc* source is limited to half the switching period. Thus, the maximum inductor current $I_{L1\ \max}$, which is chosen according to switch and diode maximum current ratings, is given by

$$|i_{L_1\max}| \le \frac{V_{DC}}{2L_1 f_{sw}}. \qquad (1)$$

Therefore, the maximum allowable output current *i*omax (which is different to the maximum rated output current) must be less than. $I_{L1\ \max}$

$$|i\text{o}\max| < |iL1\ \max| \qquad (2)$$

When $L1$ is magnetized from the *dc* source with $i_{L1\ \max}$ in the first half of the switching period, $L1$ should deliver all its stored energy in the remainder of the period.

The longest time needed for $L1$ energy to be released is when C_1 voltage and the output current are both zero. Assuming C_1 voltage is zero and L_1 initial current (the instant the inductor starts to charge the capacitor) is $i_{L1\ \max}$, then

$$i_{L_1} = i_{L_1\max}\cos\left(\frac{t}{\sqrt{L_1C_1}}\right) \qquad (3)$$

To allow $iL1$ to reach zero, the second period must be greater than or equal to a quarter of the reciprocal of the L_1–C_1 natural frequency, i.e.

$$f_{\mathrm{sw}} \le \frac{1}{\pi\sqrt{L_1C_1}}. \qquad (4)$$

When the inductor transforms energy from the capacitor, back to the *dc* source, the peak inductor current at the end of the first period should not exceed $i_{L1\ \max}$. The worst case occurs when the capacitor voltage is a maximum, then the inductor current is

$$i_{L_1} = v_{o\max}\sqrt{\frac{C_1}{L_1}}\sin\left(\frac{t}{\sqrt{L_1C_1}}\right), \qquad \text{for } t \le \pi\sqrt{L_1C_1}. \; \ldots \qquad (5)$$

Thus

$$|i_{L_1\max}| \ge |v_{o\max}|\sqrt{\frac{C_1}{L_1}}. \qquad (6).$$

IV. Simulations and practical results

The block diagram used for the simulation is shown in the Fig 7. It uses PI and P controller to generate the PWM signal for Z_1 and Z_2 switches. The PWM for H-bridge can given through pulse generator since it is operated at 50Hz.

Simulations have been carried out using MATLAB simulink software package. The proposed topology of the inverter has been implemented using circuit parameters given in Table 1. The input voltage is varied from 100 to 400V (*dc*) with corresponding change in the amplitude of the reference of sine wave. The circuit working is examined both in boost and buck mode. Simulation circuit for unidirectional buck-boost single phase voltage source inverter is shown in Fig 8. Fig 9 shows the simulink model of H-bridge with LC filter.

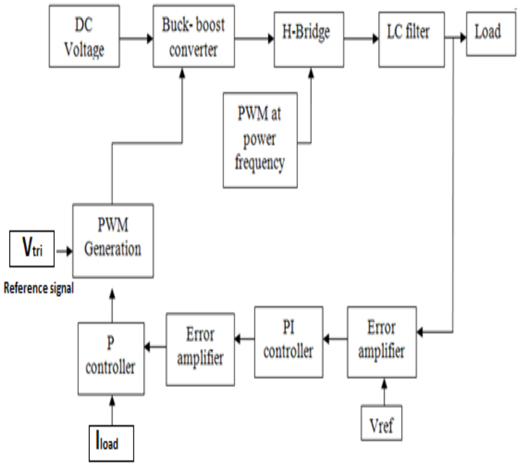

Fig 7: Block diagram of the buck-boost single phase voltage source inverter.

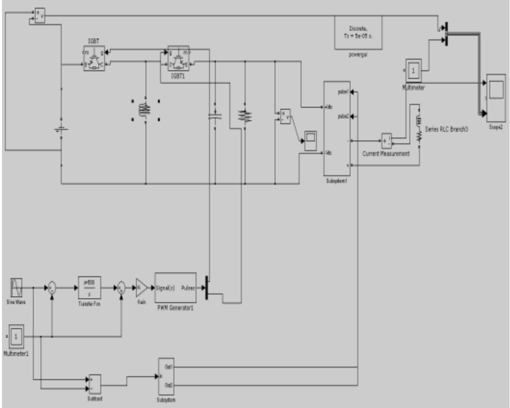

Fig 8: Simulation circuit for unidirectional buck-boost single phase voltage source inverter.

Table 1: System parameters

L_1	$100\mu H$	P_v	$0.3V/A$	F_{sw}	$20kHz$	P_i	0.04
C_1	$50\mu F$	K_v	$600V/A/s$	F_s	$50Hz$		

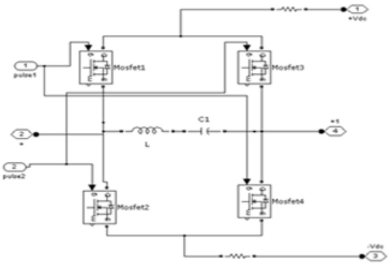

Fig 9: Simulink model of H bridge inverter with LC filter

The proposed topology of the inverter is implemented using circuit parameters given in table 1. The input voltage is varied from 100 to 400V (DC) with corresponding change in amplitude of the reference value of sine wave. The circuit working is examined both in boost and buck mode. Following are the analysis of the same.

4.1 Boost operation.

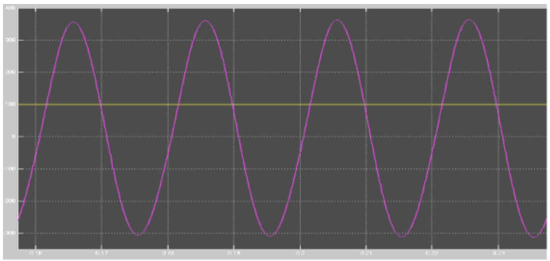

Fig 10: The snap shot of output voltage 650V peak-peak, 50Hz, *ac* with input voltage of 100V DC and reference sine wave voltage amplitude set at 45V

In this case the proposed topology of the inverter circuit acts a boost inverter since the reference sine wave voltage amplitude applied is 45V. The reference sine wave voltage amplitude set in controller circuit is greater than 16V, the proposed topology the inverter acts as a boost inverter, converting 100V *dc* input voltage to output voltage of 650V peak–peak *ac*, 50Hz Fig 10 shows the boost operation of the proposed inverter topology. When input *dc* voltage is 100V and reference sine wave voltage amplitude set at 45V, the output voltage obtained is 650V peak-peak, 50Hz, *ac*.

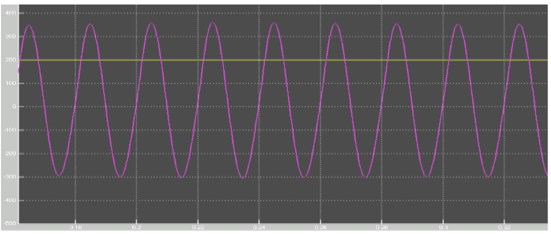

Fig 11: The snap shot of output voltage 650V peak-peak, 50Hz, *ac* with input voltage of 200V DC and reference sine wave voltage amplitude set at 26V.

Fig 11 shows operation of the proposed topology of the inverter circuit, as a boost inverter since the reference sine wave voltage amplitude applied is 26V. The reference sine wave voltage amplitude set in controller circuit is greater than 16V, the proposed topology the inverter acts as a boost inverter, converting 200V *dc* input voltage to output voltage of 650V peak –peak, 50Hz *ac*.

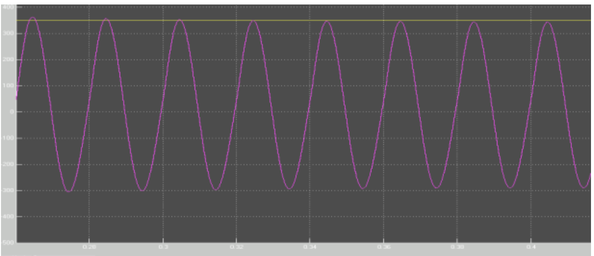

Fig 12: The snap shot of output voltage 650V, peak-peak, 50Hz,*ac*, when input voltage of 325V *dc* is applied and reference sine wave voltage amplitude set at 16V.

Fig 12 shows operation of the proposed inverter circuit topology acting neither as a boost inverter nor a buck inverter since the reference sine wave voltage amplitude applied is 16V. The reference sine wave voltage amplitude given to controller circuit is equal to 16V, which is the nominal value of the voltage for the designed control circuit. For this value of the reference voltage, the proposed topology of the inverter converts input *dc* voltage to corresponding value of output *ac* voltage without boosting or bucking the magnitude input voltage. Thus converting input voltage of 325V *dc* to output voltage of 650V, peak-peak, and 50Hz *ac*.

4.2 Buck operation

Whenever input voltage from PV cells to inverter circuit is greater than grid voltage then the inverter operates in buck mode. In order to operate the inverter in buck mode, amplitude of reference voltage should be set to value less than 16V.

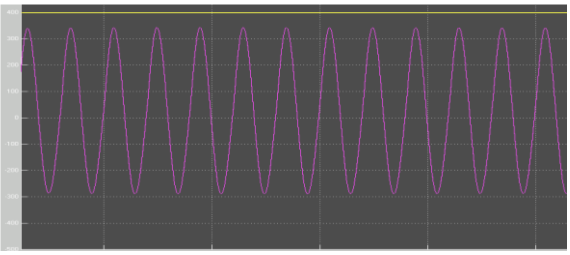

Fig 13: The snap shot of output voltage 650V, peak-peak, 50Hz *ac*, when input voltage of 400V *dc* is applied and reference voltage amplitude set at 13V

Fig 13 shows operation of the proposed topology of the inverter circuit, as a buck inverter since the reference sine wave voltage amplitude applied is 13V. The reference sine wave voltage amplitude set in controller circuit is lesser than 16V, the proposed topology the inverter acts as a buck inverter, converting 400V *dc* input voltage to output voltage of 650V peak –peak, 50Hz, *ac*.

Different output voltages for different input *dc* voltages that are carried during simulation are briefly summarized in Table 2.

Table 2: Summary of simulation results

Sl.No	**V_{ref}**	**V_{dc}**	**$V_{peak-peak}$**
1	45V	100V	650V
2	32V	150V	650V
3	26V	200V	650V
4	18V	300V	650V
6	16V	325V	650V
7	15V	350V	650V
8	13V	400V	650V

V. Conclusion

Simulation of unidirectional of buck- boost single phase voltage source inverter has been carried out using MATLAB simulink software package. From simulation results it is seen the proposed topology of buck-boost single phase voltage inverter works exceptionally well producing an *ac* sine wave output depending upon the reference sine wave amplitude given to control circuit. The input voltage to power circuit was varied from 100V to 400V. From simulations results it can seen that if the reference sine wave amplitude is set 16V, which is the nominal value for the simulation control circuit, the voltage source buck-boost inverter neither bucks or boosts the input voltage however it inverters the *dc* voltage to 650V peak-peak 50Hz, *ac* voltage. If the reverence sine wave amplitude given to control circuit is greater than 16V then the proposed topology of inverter acts as boost inverter, inverting the input voltage to 650V peak-peak *ac*, 50Hz and vice versa. From simulation results it can summarized that the proposed topology of the inverter circuit operates for wide range of *dc* input voltage producing a sinusoidal *ac* voltage, 50Hz output.

The proposed inverter is applicable as a utility interactive inverter for distributed generating systems and harmonic elimination applications. The proposed inverter uses six switches. The low switching frequency of the output H-bridge reduces inverter switching losses and costs, compared to six and eight switch-based techniques.

The drawbacks of this inverter, compared to the traditional H-bridge inverter are: relatively high cost (six switches) and relatively high switching losses in two of the six switches.

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