DESIGN & SIMULATION OF BUCK-BOOST CONVERTER MODULATION TECHNIQUE FOR SOLAR APPLICATION

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ABSTRACT :
In this paper, a single-phase single stage transformerless photovoltaic (PV) inverter for residential application is presented. The inverter is derived from a buck-boost converter along with a line frequency unfolding circuit which will be used to supply the generated photovoltaic energy to load (Grid/Stand Alone). Interfacing a solar inverter module with the load involves three major tasks. One is efficiency, the second is to inject a sinusoidal quantity into load and the third is the power quality. Since the inverter is connected to the grid, the norms given by the utility companies must be obeyed. Due to its novel operating modes, high quality (without filter) and efficiency can be achieved, because there is only one switch in buck-boost converter operating at high frequency and rest of the switches of unfolding circuit is operated at fundamental frequency only. This paper contains theoretical analysis and simulation result of this buck-boost converter based inverter for off grid. This shows the comparison of the norms with the simulation result of the product in terms of power quality and efficiency.

KEY WORDS *: Off-Grid, high quality, high efficiency, buck-boost, inverter, photovoltaic (PV).*

1. Introduction

Electricity is most essential part required for human survivor and for the growth of any nation. But the fact is that, electricity is not available naturally and it has to be converted from other source of energy which may be renewable (solar, wind, fuel cell) or non-renewable (fossil fuel). World's 79% energy consumption is coming from the fossil fuel and India's electricity generation of 88.4% are consuming non-renewable source for generation. The World Energy Forum has predicted that fossil based oil, coal and gas reserves will be exhausted in less than another 10 decades which create the shortage of the world's energy along with environmental pollution problems, protecting the energy and the environment have become the major concerns for human beings and critical part of the solution will lie in promoting renewable energy technologies. [1-4]

Solar PV-based generation does have its drawbacks but its having more advantages to over shadow that drawback and The Electricity Act, 2003 has stimulated captive power generation of solar in the country.[5] Due to above advantages the India and particular Gujarat having great potential to generate solar electrical power generation

Solar power generation was increased by 20 to 25% in last 20 year. Solar photovoltaic (pv) cells convert sunlight directly to electricity without pollutant emission. This electricity generation is effected by physical and environmental parameters such as the solar radiation and cell temperature on pv cell.[6,7]

PV power supplied to the utility grid is gaining more and more attention nowadays [9-13], hence various standard mentioned by different grid monitoring authorities are has to be follow. This standard are deals with issues as power quality, detection of islanding operation, DC current injection etc. Different utility are follow the different standards which are depend on the nation, national policy, types of utility, types of consumer, power rating etc..[5,8,14] Numerous inverter circuits and control schemes can be used for PV power conditioning system (PCS). For residential PV power generation systems, single-phase utility interactive inverters are of particular interest [15-18]. This type of application normally requires a power level lower than 5 kW[16,19] and a high input voltage stack that provides a dc voltage around 400V. However, depending on the characteristics of the PV panels, the total output voltage from the PV panels varies greatly due to different temperature, irradiation conditions, and shading and clouding effects. Thus, the input voltage of a residential PV inverter can vary widely, for example, from 200 to 500V, and can be quite different from the desirable 400-V level. Therefore, a dc–dc converter with either step-up function or step-down function or even both step-up and step-down functions is needed before the dc–ac inverter stage. Such a dc–dc converter in conjunction with a dc–ac inverter arrangement has been widely used in the state-of-the-art PV PCS.

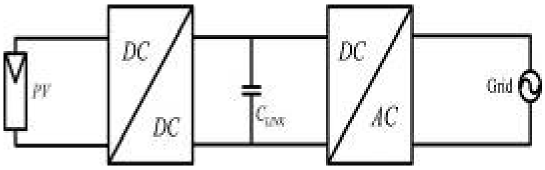

Fig. 1.Conventional two stage PV.

Fig. 1 shows the block diagram of the PV PCS which has two-stage high-frequency power conversion in cascaded configuration with dc link in the middle [20-24]. In this structure, the dc-bus voltage should be boosted from the PV array, and the dc–ac stage can be a voltage-source-type high-frequency inverter. Another option is to use a line-commuted inverter along with an isolated dc–dc stage [25–27]. Also, many nonisolated single-stage boost or buck–boost derived inverter topologies have been developed [28-31]. Their major drawbacks are limitation of input-voltage range and/or requirement of two input sources [32-33]. With recent changes in electric code that allows ungrounded PV panels, it is possible to replace the isolated dc–dc with nonisolated or transformerless dc–dc [34]. Without the transformer, the dc–dc stage will be more reliable and cost effective.[35] If the dc–dc stage can produce a rectified sinusoidal output, then the dc–ac stage only needs to operate in line frequency by simply determining the polarity of the dc–dc output.

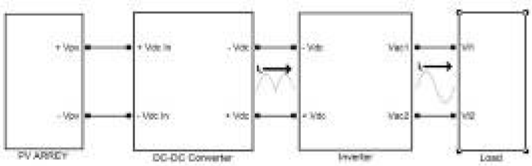

Fig. 2. Buck-Boost based PV inverter.

In this paper, a buck-boost type dc–dc converter is proposed as the first stage with regulated output inductor current, and a full-bridge unfolding circuit with 50 or 60-Hz line frequency is applied to the dc–ac sage, which will unfold the rectified sinusoid current regulated by the dc–ac stage into a pure sinusoidal current, as shown in Fig. 2. Since the circuit runs either in boost or buck mode, its first stage can be very efficient if the low conduction voltage drop power MOSFET and ultrafast reverse recovery diode are used. For the second stage, because the unfolding circuit only operates at the line frequency and switches at zero voltage and current, the switching loss can be omitted. The only loss is due to the conduction voltage drop, which can be minimized with the use of low on-drop power devices, such as thyristor or slow-speed insulated gate bipolar transistor (IGBT). Since only the buck-boost dc–dc converter operates with high-frequency switching all the time in the proposed system, the efficiency is improved.[36] Also, because there is only one high-frequency power processing stage in this complete PCS, the reliability can be greatly enhanced.[37]

2. Operation Principle

Before going further let's just understand Basic DC-DC Converters[38].In many industrial application , it is required to convert a fixed-voltage dc source into a variable–voltage dc source. A dc-dc converter converts dc to dc and simply known as a dc-dc converter. A dc converter can be considered as dc equivalent to an ac transformer with a continuously variable turn's ratio. Like a transformer, it can be used to step down or step up a dc voltage source.

Basically there are three types of the dc-dc converter which are:

(i).Buck Converter- the average output voltage Va is always less than the input voltage of converter its voltage equation is written as under

$$Va = K \cdot Vs \qquad (1)$$

Where K=Duty cycle of chopper 0<k<1

(ii) Boost Converter- The average output voltage Va is always greater than the input voltage Vs of converter, its voltage equation is written as under.

$$Va = Vs \frac{1}{(1-K)} \qquad (2)$$

(iii) Buck-Boost Converter- The average output voltage Va is less than or greater than the input voltage Vs of converter, it will be decided by value of k and its voltage equation is written as under. Output voltage of this converter is having opposite polarity than the input voltage hence it also known as Inverting converter. The circuit arrengment of buck boost converter is shown in Fig. 3.

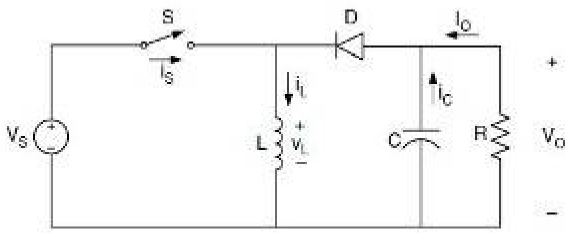

Fig. 3. Buck-Boost Converter.

$$Va = Vs \frac{K}{(1-k)} \qquad (3)$$

When O<K<0.5-Converter operate in Buck Mode.
0.5<K<1- Converter operate in Boost mode.
0.5=k- Converter operate in Ideal mode.

A. Boost Mode

When the PV panel's voltage is lower than the instantaneous reference voltage, it will operate in boost mode, in which *S* will be switched ON and OFF with the duty cycle 0.5<K<1 which can be found from eq. (3)

B. Buck Mode

When the PV panel's voltage is higher than the instantaneous reference voltage, it will operate in buck mode, in which *S* will be switched ON and OFF with the duty cycle 0<K<0.5 which can be found from eq. (3)

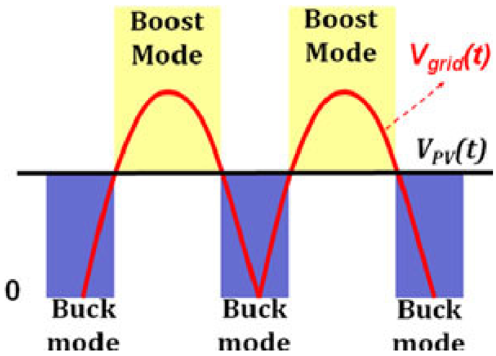

Fig. 4. Operation mode.

Thus, if the PV panel's voltage is lower than the system's peak voltage, the PV inverter will switch between buck mode and boost mode depending on the instantaneous system voltage as shown in Fig. 4. However, if the PV panel's voltage is higher than the system's peak voltage, it will always run at buck mode. Instead of a dc bus in the middle, the voltage across the capacitor *C* in boost/buck PV inverter varies with the system, if PV panel's voltage is lower than the System's peak voltage as shown in Fig. 5. However, if PV panel's voltage is higher than system's peak voltage, *C* 's voltage will be the same as the PV panel's voltage.

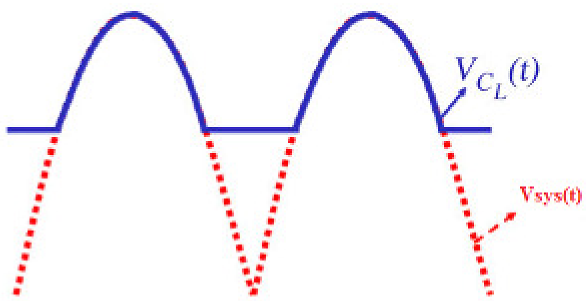

Fig. 5 Capacitor *C* 's voltage.

3. Power Schematic and Simulation Result

The Fig. 6 shows the power schematic of the proposed system. Here Buck-Boost converter generates sinusoidal rectified output voltage from varying DC voltage of PV array which converted into the AC Voltage by using simple full bridge inverter operate at fundamental frequency.

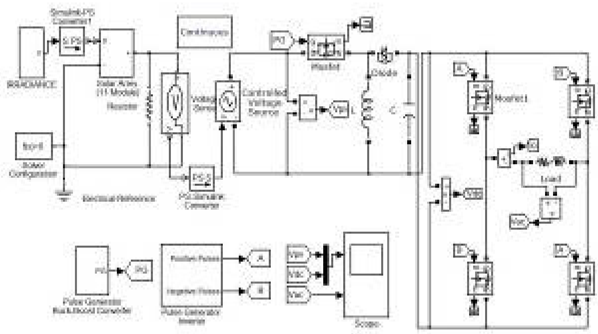

Fig. 6. Off-Grid PV Solar Power Generation Simulation Circuit Diagram.

Fig. 7 is the half simulation circuit of Fig.1. which has two-stage high frequency power conversion configuration where dc link is replaced with DC source. In this structure, the dc-ac stage can be a voltage source type high frequency inverter.

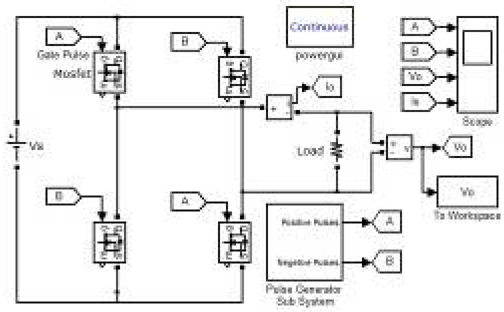

Fig. 7. DC-AC Stage Voltage Source High Frequency Inverter.

Simulation circuit shown in fig. 7 is use to compare the result of the proposed simulation shown in fig. 6 in terms of power quality required which are the most important terms while we are connecting solar power generation with utility grid.

Simulation result of the circuit shown in fig. 6 and fig. 7 and its comparison are shown in the follow.

3.1 Simulation Result of Single Stage Configuration

Assuming constant temperature and Variable irradiation solar array providing varying voltage to DC-DC converter front-end Figure 4.8 shows result of the simulation. To varying irradiance from 600, 1000 and 700 w/m^2 at particular time distance during simulation.

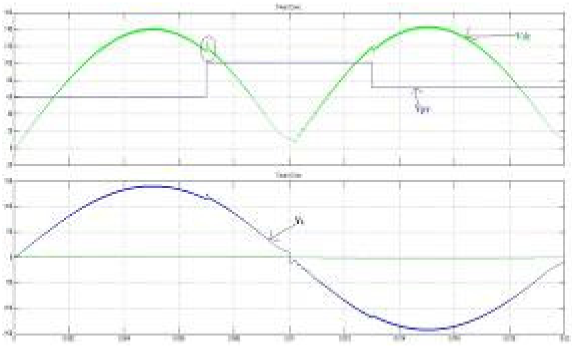

Fig. 8 Simulation Result of Solar PV generation for Off-Grid AC Sinusoidal Load(Vpv=Varying)

Where Vpv=Solar PV Voltage =60, 100 and 70 V
Vdc=Buck-Boost Converter Output Voltage=145V Peak
Vac=V_L=Voltage Across Load=145 Sinωt
V_R=Reference Voltage For Controller =160 Sinωt

FFT analysis of this simulation output voltage is given in the fig. 9 which contains the signal to be analyzed and its harmonic analysis in percentage with the fundamental frequency. Table 1 shows the result of the analysis in tabular form of harmonic order, DC component added in AC system and Total Harmonic Distortion(THD%) in the AC system.

Table 1 FFT Analysis (Fig. 8)

DC component = 0.2842			
Fundamental = 144.1 peak (101.9 rms)			
Total Harmonic Distortion (THD) = 1.67%			
Maximum harmonic frequency used for THD calculation = 5536050.00 Hz (110721th harmonic)			
0 Hz (DC):	0.20%	500 Hz (h10):	0.18%
50 Hz (Fnd):	100.00%	550 Hz (h11):	0.22%
100 Hz (h2):	0.82%	600 Hz (h12):	0.03%
150 Hz (h3):	0.36%	650 Hz (h13):	0.19%
200 Hz (h4):	0.23%	700 Hz (h14):	0.09%
250 Hz (h5):	0.34%	750 Hz (h15):	0.21%
300 Hz (h6):	0.19%	800 Hz (h16):	0.16%
350 Hz (h7):	0.22%	850 Hz (h17):	0.22%
400 Hz (h8):	0.16%	900 Hz (h18):	0.04%
450 Hz (h9):	0.22%	950 Hz (h19):	0.20%

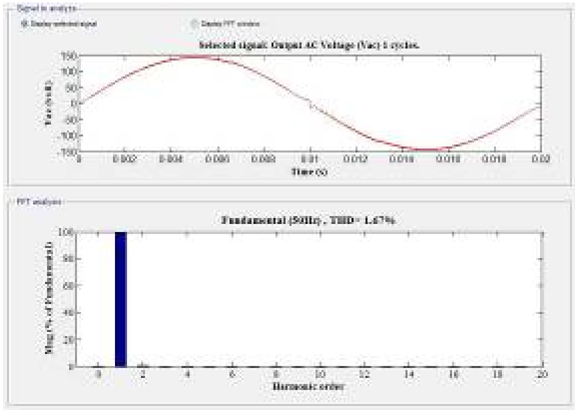

Fig. 9 FFT Analysis of V_L Solar PV generation for Off-Grid AC Sinusoidal Load (Vpv=Varying)(Fig. 6)

3.2 Simulation Result of Two-Stage Configuration

[A] DC-AC Stage Voltage Source Inverter

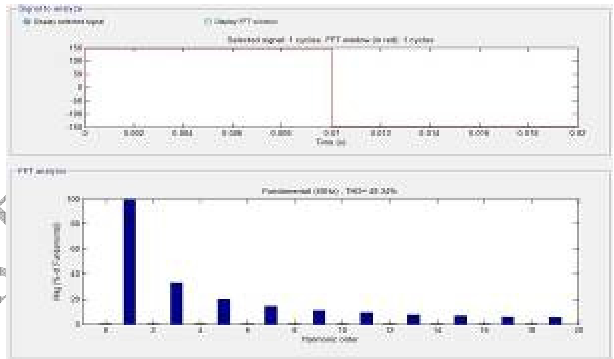

Fig. 10 FFT Analysis of DC-AC Stage Voltage Source Inverter (Tow Level). (Fig. 7)

[B] DC-AC Stage Voltage Source High Frequency Inverter (Tow Level)

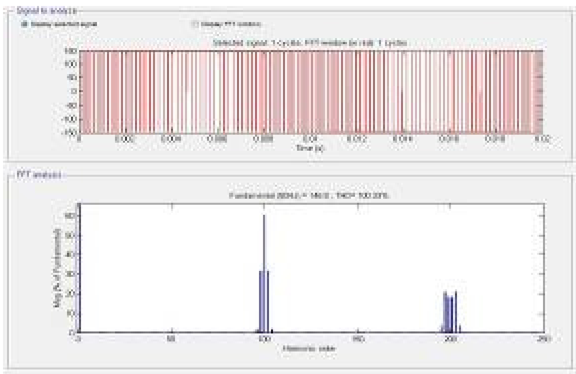

Fig. 11 FFT Analysis of DC-AC Stage Voltage Source High Frequency Inverter (Two Level) (Fig. 7)

Fig. 10 shows the FFT analysis of the simple square wave full bridge(FB) two level inverter switching at fundamental frequency which does not have a sine wave and contains THD equal to 48.34 % of the fundamental and having lower order harmonic (3^{rd},

5^{th} and 7^{th}) dominating[38].While Fig. 11 shows the FFT analysis of the full bridge two level high frequency inverter which does not have sine wave and contains THD equal to 100.30% of fundamental. It doesn't contain lower order harmonic but it contains higher order harmonic near at the ratio of carrier frequency to the fundamental frequency and its multiplication.

Table 2 IEEE 1547 requirements.[16]

Nominal Power	30 kW
Harmonic Currents	(2-10) 4% (11-16) 2% (17-22) 1.5% (23-34) 0.6% (>35) 0.3% THD %%
DC Current Injection	< 0.5% of Rated Output Current
Abnormal Voltage Disconnection	V < 50% or V>137%6 cycles 50%< V < 88% or 110%< V < 137% 120 cycles
Abnormal frequency disconnection	f < rated – 0.7 Hz 6 cycles f > rated + 0.5 Hz 6 cycles

From the above study and simulation it has been found that by using single stage Buck-Boost inverter, sinusoidal voltage can be generated with very low THD without requirement of any filter and less switching loss as inverter works on fundamental frequency while on the other side in two stage configuration we find higher percentage of THD and it not having sinusoidal wave hence it requires filter to make waveform sinusoidal and to reduce the THD.

4. Conclusion

This paper analyzed a single-phase, single stage high power quality buck-boost converter based on transformerless off-grid PV inverter. The following conclusion is drawn from the work. A high power quality buck-boost converter based on single-phase, single stage PV inverter is analyzed. The first part i.e. converter part operates in either boost or buck mode; thus, it has a wide input voltage range, which is good for PV application. The second part i.e. inverter part is composed with power frequency unfolding circuit based on the direction of the off-grid reference signal. Therefore from power processing point of view, this inverter is a single stage inverter. Because it processes power either as a buck converter or a boost converter, high power quality can be achieved.

Now we can say that, we can propose a single-phase, single stage buck-boost converter based high quality transformerless grid PV inverter.

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