Improving power flow management in a traditional Distributed Generation with improved DC-DC converter and Inverter topologies

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ABSTRACT

The penetration of distributed generation (DG) is increasing around the world. Renewal sources based DGs are particularly gaining popularity. Advances in power electronics have particularly helped to implement efficient DG systems. A traditional DG system consist of a Power source, a two level DC-DC boost converter to condition DC source as well as increase voltage level, a half bridge inverter to convert DC to AC for transmission and consumption. However in the traditional system both DC- DC converter and Inverter are inefficient. With more efficient power electronics solution available, in this paper we have proposed a three level DC-DC boost converter which reduces conduction and switching losses and a full bridge inverter which requires only half of DC bus voltage as compared to traditional approach. Simulation models have been created in MATLAB. Results show that in the new proposed approach conduction losses have been reduced by 15 times and DC bus voltage is halved.

Keywords: *Distributed generation, DC-DC boost converter, H bridge Inverter, Solar PV, MATLAB, SIMULINK.*

I : INTRODUCTION

History of Distributed generation started from the start of 20^{th} century i.e. post 1900, when in UK there was no national transmission system. In the year 1919, total 570 electricity utilities were operating 439 generating stations. In the absence of transmission system, generators were directly connected to local distribution networks [1].

The penetration of distributed generation (DG) is increasing around the world especially in developed countries. They usually work at medium and low voltages (MV and LV). These days distributed generation mainly includes Solar-cell, wind power, fuel cell (FC) plants and storage devices as local energy sources [2]. These sources are more popular due to many advantages like lesser power losses, improvements in voltage level and these sources can be connected in radial power line with low losses [3-4]. It is expected that Distributed generations based on Solar photovoltaic modules, wind turbines (WTs) and other renewable energy sources (eg. Biogas) will play a key role in future electricity supply. These technologies are herein collectively called as distributed energy resources (DERs) [5].

The major credit for such popularity and success of Distributed generation goes to advancements in power electronics technology. With the help of high end technologies it has now become possible to handle the complexity in power flow control in a distributed generation. A typical DG system consists of a DC source. If an AC source is used then it also employs a rectifier. Finally a voltage source inverter is used to convert DC back to AC [6]. In this paper we have discussed a photovoltaic based distributed generation connected to a grid. Power flow stages from Solar cell to grid include a DC-DC boost converter and a DC to AC inverter.

The rest of the paper is organized as follows: Section-2 discusses traditional topologies used in referenced literature for DC-DC boost converter and DC-AC inverter to be used in a typical Photovoltaic Cell based distributed generation system. Section-3 proposes a new approach with improved topologies both for DC-DC converter and DC-AC converter. Section-4 provides a simulation model of both traditional approach and new proposed approach. Simulation results are also discussed and compared. Section-5 concludes this paper.

II : Distributed generation characteristics : Traditional approach.

In a DG, electric power generation is distributed and not a lumped generation. Because of this feature different sources can collectively provide additional power as in when it is required. As both generation and consumption is distributed, it leads to a more reliable structure. However control of such system becomes complex which requires a robust control strategy and protection. [7]

So to provide better control on generated AC output power, a dc-dc converter is employed to equalize the dc link voltage before it can be inverted and fed to the grid. It also helps to deliver reliable power even during fast transients as required by local loads. Whereas a dc-ac converter is used to guarantee power quality both to the local loads and the grid. [4]. A general diagram of power stages used in a typical DG is shown below :

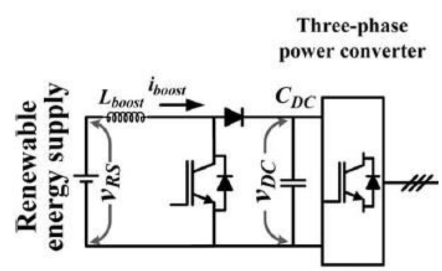

Fig-1 : General diagram of power stages in a DG

A. DC-DC Converter

As discussed before dc-dc converter is used between a power source and DC source inverter. This converter serves two purposes. One it helps to draw maximum power from power source. For example in case of photovoltaic cells it is essential to operate it at Maximum power point to capture maximum possible power from the source. Failing to do we may not be able to draw maximum power from a photovoltaic cell. Hence a tracking algorithm to run solar cells at MPPT (Maximum power point tracking) is discussed in [8]. Secondly, natural power sources are not ideal Voltage power sources. It means that such sources may not provide infinite current and may not provide instantaneous reaction to fast transients in the load. Poor reaction to such transients will lead to power disturbances in feeder side which is not desirable. Hence DC-DC converter increases the reaction response of natural power source because they store some energy either in capacitor or inductors used in its circuit. This stored energy supports the original power sources during transients and sudden power demand and thus minimizes disturbances in the feeder current.

To keep the converters operating in a stable mode, proportional-integral (PI) controllers were used as a control technique. [4] [7] Figure-2 shows the control diagram. The main aim is to provide stable *Lboost* current and dc voltage (*vDC*). A method based on phase-margin (*mf*) and cutoff frequency (*FCL*) was used to obtain the PIs constants [base], [4], where the open loop gain (*GOL*), angular frequency (*ωFCL*), and *mf* define the PIs constants (*kprop* and *kint*) as

$K_{prop} * (G_{ol} / W_{Fcl}) = 1$ …………………………………..(1)

$K_{int} = K_{prop} * (W_{fcl} / \tan(mf))$ ………………………..(2)

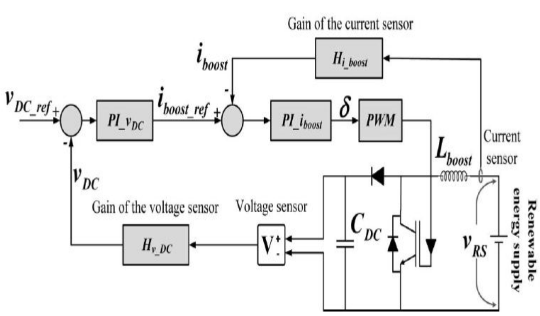

Fig-2 : Control diagram of DC DC boost converter

Classical Boost converter

The DC-DC boost converter in [4] [7] [9] and in many other works is one of the most popular converter type and quiet widely used. Many papers have used this topology. As mentioned in [9] classical bi-directional topology is shown fig-3.

As shown in diagram converter has three basic components, two MOSFETS/IGBTs and an inductor. This topology supports both buck and boost mode, but for our study only boost mode is relevant. In boost mode, T2 is always off and T1 switches between on and off with certain frequency and duty cycle. When T1 is on inductor is charged by Ucap or power source. When T1 is off Ucap or power source together with inductor, boosts voltage through diode D2 of transistor T2.

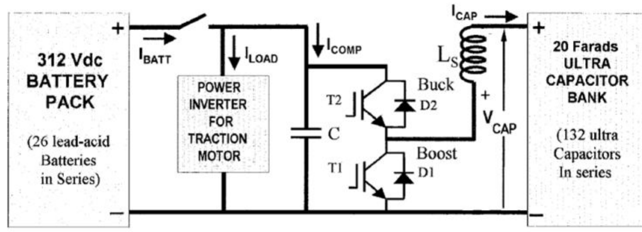

Fig-3 Classical DC DC converter topology

There two major drawbacks of this topology. Firstly, as only one inductor is used for lower ripples in output current of voltage high value of inductor is required. Assuming that inductor resistance is proportional to its length which in turn is proportional to inductance value, we can safely conclude that higher value inductors will have higher conduction losses. Second major drawback is high switch voltage rating. As we know that switching losses depends on three factors namely switching voltage, switching current and switching frequency. So this topology has more switching losses with increasing boost voltage ratio. [10]

B. DC-AC Converter

As discussed before DC-AC inverter does the main task of converting DC energy into AC energy which is preferred source both for distribution as well as consumption. [4] [7] have proposed a two level inverter topology as shown in fig – 4.

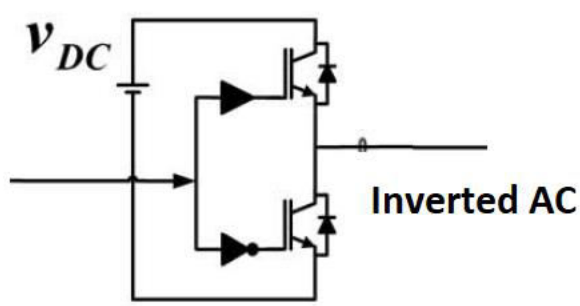

Fig - 4 : Half bridge inverter topology

Like Boost converter, PI controller based closed-loop controls of the output current and voltage were implemented to guarantee inverter voltage quality. To improve this compensation capability, a feed-forward of the reference voltage was also used to compensate the residual error in the closed-loop gain at low frequencies. To improve the control response of the output voltage regulator for fundamental and harmonic components, a resonant controller is placed in parallel along with the conventional voltage PI, thereby reducing the converter impedance [4]

The major drawback of this topology is that peak to peak voltage of inverted AC voltage is equal to DC bus voltage. Hence to get higher AC voltage higher DC bus voltage is required. As we know that losses in DC DC boost converter increases considerably for higher boost ratio. Hence implementing this AC inverter topology will in effect lead to higher losses in DC DC boost converter.

III : Distributed generation characteristics : New approach.

So in previous section we concluded that traditional DGs have following drawbacks:

1. Higher conduction losses in DC-DC converter due to use of high value inductor.

2. Higher switching losses due to higher switching voltage across switching devices

3. Inverter generates AC voltage with peak to peak voltage equal to DC bus voltage.

In order to remove these drawbacks in this paper we have proposed two solutions. First one is to use a three level DC-DC boost converter as proposed in [10]. Using this topology we can effectively reduce higher conduction losses and switching losses. Second one is to use H bridge inverter which can generate peak to peak AC voltage twice that of DC bus voltage as discussed in [11]

A. Three level DC-DC boost converter :

[10] proposes a three level DC-DC converter which support both buck and boost mode. For our case only boost mode is relevant. Circuit diagram of three-level bidirectional converter is shown fig-5.

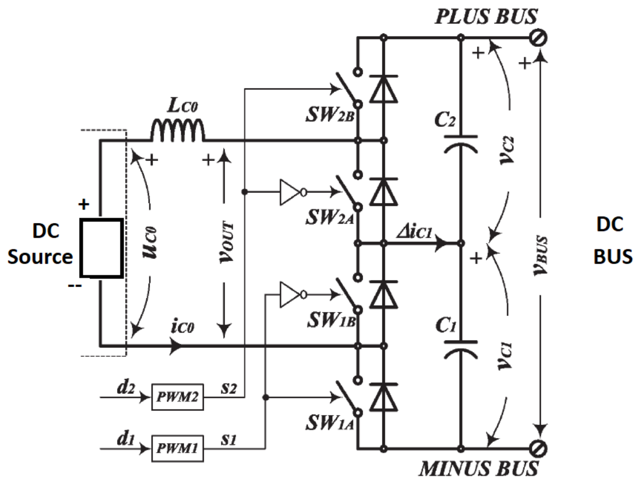

Fig-5 Three level DC DC converter topology

The converter is composed of four current-bidirectional switches, a filter inductor L_{C0}, and two input filter capacitors C_1 and C_2. The switches are the insulated-gate bipolar transistor (IGBT) or MOSFET with freewheeling diodes. The input filter capacitors play a role of the capacitive voltage divider that splits the dc bus voltage v_{BUS} into two equal voltages. As it is clear from the circuit diagram that inductor needs to charge only one capacitor at a time and that too at half the DC bus voltage. This reduces the stress on IGBT/Mosfet switches thereby reducing switching losses. Also for same voltage ripples smaller inductor is required there by reducing inductor size as well as conduction losses.

B. H bridge Inverter

[11] proposes H bridge based full bridge inverter. The circuit diagram is shown in fig-6. A single phase full bridge inverter is constructed by four switching elements T1 to T4. Switching on of T1 and T4 produces an output voltage of Vs across the load and switching on of T2 and T3 produces an output voltage of -Vs. For switching on the devices the gate pulses were applied using unipolar switching SPWM technique. Using bridge we can produce AC output with peak to peak voltage twice the DC bus voltage.

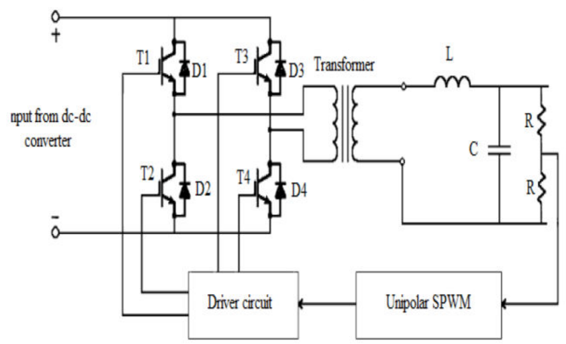

Fig-6 : H bridge inverter topology

IV: Simulation Results

In order to demonstrate that new approach can reduce substantial losses compared to traditional approach we created simulation models in MATLAB both for traditional approach as well as new approach.

Fig-7 shows the simulation model for traditional approach. It includes PV cell as DC source, a DC DC boost converter, a DC bus, an inverter and a resistive load. Parameters chosen for traditional approach simulation model is as follows. PV cell is assumed to provide 100 volts. Final AC peak to peak waveform was chosen to be 400 volts. Hence in traditional approach DC bus voltage should also remain at 400 volts. Boost ratio hence was kept at 4 times. Simulation has been carried for 5 seconds.

For traditional approach, DC bus waveform, AC waveforms and conduction losses waveform is shown below :

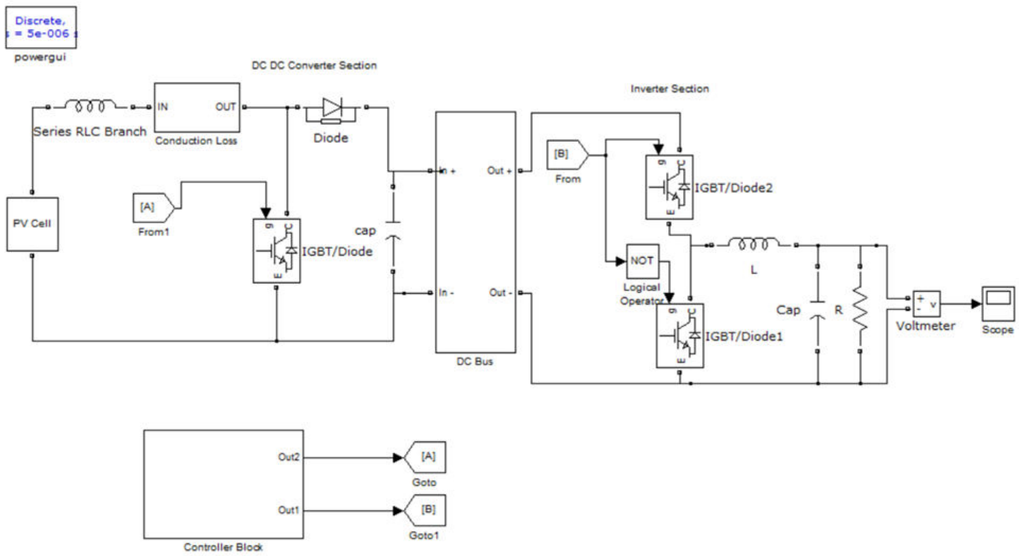

Fig-7 : SIMULINK Model for Traditional approach

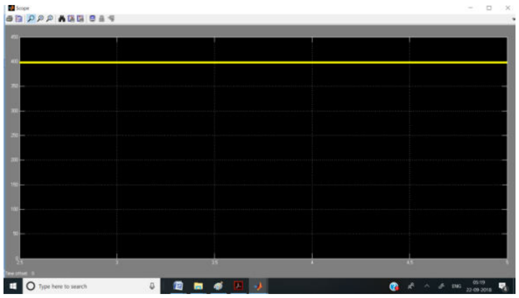

Fig-8 : Traditional : DC bus waveform (400 Volt)

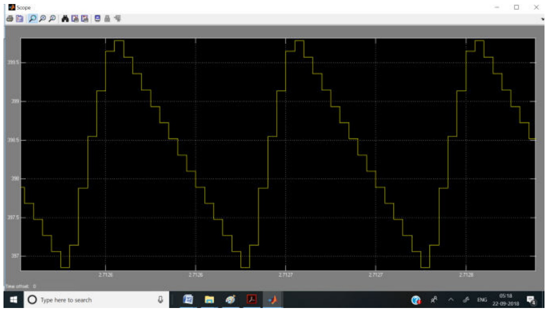

Fig-9 : Traditional : DC bus voltage ripples (397 to 400 volt approx)

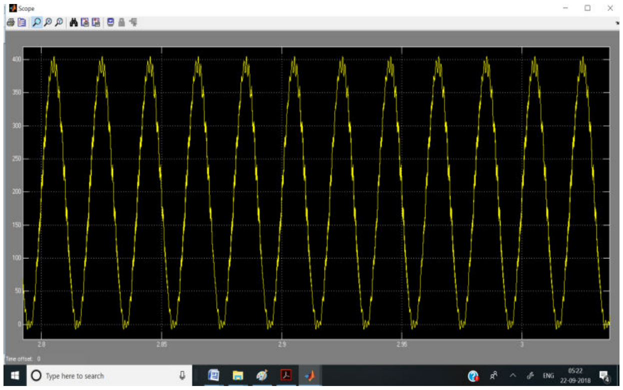

Fig-10 :Traditional : AC waveform (peak to peak 400 volts)

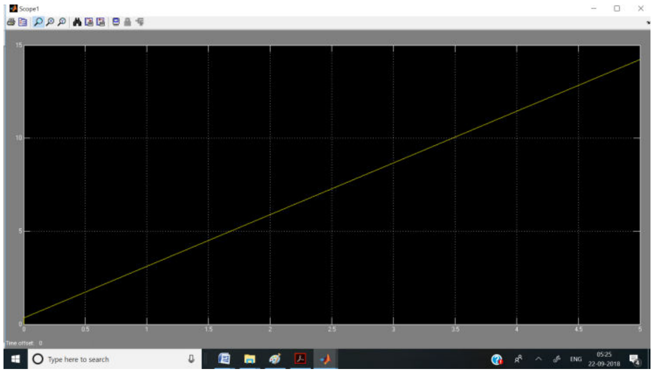

Fig-11 : Traditional: Conduction losses (15 watts per 5 secs)

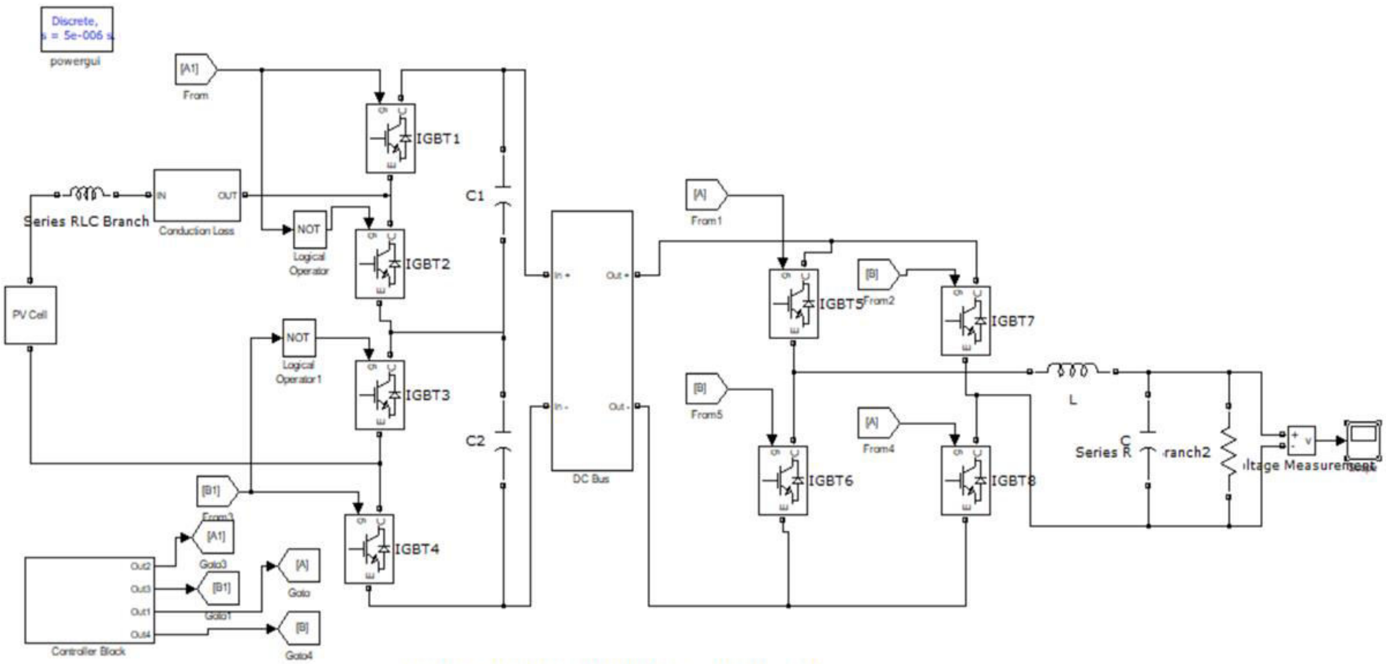

Fig-12 : Simulation Model for new approach

Fig-12 shows the simulation model for new approach. It includes PV cell as DC source, a DC DC three level boost converter, a DC bus, an H-bridge inverter and a resistive load. Parameters chosen for new approach simulation model is as follows. PV cell is assumed to provide 100 volts. Final AC peak to peak waveform was chosen to be 400 volts. Hence in new approach DC bus voltage should remain at 200 volts. Boost ratio hence was kept at 2 times. Simulation has been carried for 5 seconds.

For new approach, DC bus waveform, AC waveforms and conduction losses waveform is shown below :

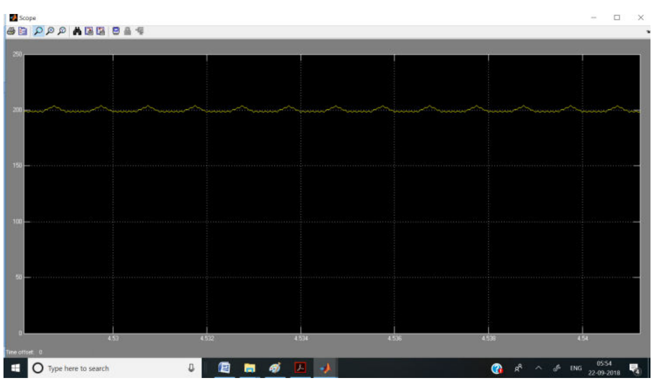

Fig-13 : New : DC bus waveform (200 Volt)

Fig-14 : New : DC bus voltage ripple (198 volt to 204 volt approx)

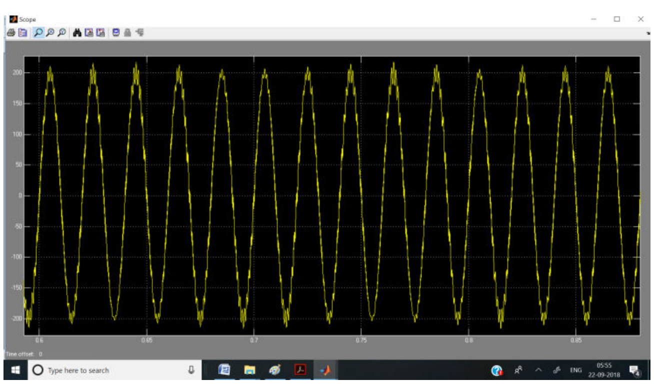

Fig-15 : New : AC waveform (peak to peak 400 volts)

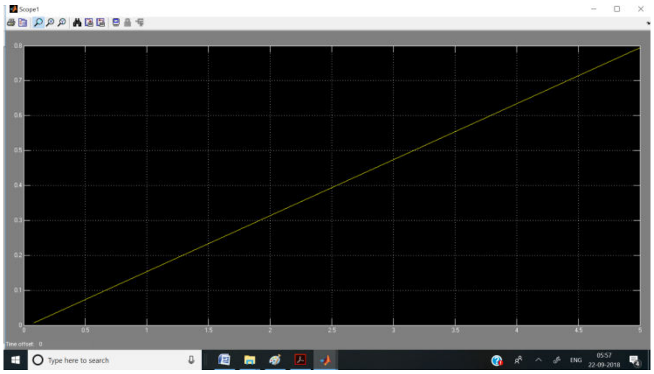

Fig-16 : New : Conduction losses waveform (0.8 watt per 5 secs)

From simulation results shown above, we can make two observations. Firstly DC bus voltage in the new approach is half as compared to traditional approach for same peak to peak AC output. Secondly a conduction loss in the new approach is less than 15 times compared to traditional approach. Please note that DC-DC converter inductor used in both models was of value 1 uH and series resistance 0.01 ohm. Similarly DC bus capacitors were of value 100 uF.

V : Conclusion

Various referred literature highlights the growing popularity of DGs. Renewable energy sources will remain main power source for most of the DG systems. Traditional DG systems employ two level classical DC DC boost converter and half bridge Voltage source inverter. The major drawback of such system is higher conduction losses due to use of higher valued inductor used and higher switching losses due to higher switching voltage across power switches. Further using half bridge inverter, DC bus voltage has to be same as peak to peak AC voltage. To remove these drawbacks a new approach is proposed which suggests use of three level DC DC converter and full H-bridge inverter. Simulation models were presented and results shows that the new approach reduces conduction losses by 15 times and required DC bus voltage for same AC voltage is halved compared to traditional approach.

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