Simulation of PV based Switched Boost Inverter for Grid connected System

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Abstract— **Introduction of reference frames in the analysis of electrical machines has turned out not only to be useful in their analysis but also has provided a powerful tool for the implementation of sophisticated control techniques. This application note gives an introduction to the theory of the most commonly used reference frames and provides routines that allow for easy conversion amongst them. Control of three-phase power converters in the synchronous reference frame is now a mature and well developed research topic. However, for single-phase converters, it is not as well-established as three-phase applications. So in this paper a single phase SRF theory is proposed for SBI. The SBI can produce an ac output voltage that is either greater or less than the available dc input voltage. Also, the SBI exhibits better electromagnetic interference noise immunity when compared to the VSI, which enables compact design of the power converter. These features make the SBI suitable for dc nanogrid applications. This paper also presents a dq synchronous reference- frame-based controller for SBI, which regulates both dc and ac bus voltages of the nanogrid to their respective reference values under steady state as well as under dynamic load variation in the nanogrid. The simulation results are obtained using MATLAB/SIMULINK software.**

Keywords— **Photovoltaic system, DC nanogrid, switched boost inverter (SBI), synchronous reference frame (SRF).**

I. INTRODUCTION

Distributed generation using renewable energy sources is gaining popularity due to environmental concerns over burning fossil fuels, deregulation of the electricity industry, and technological advances in power electronics and renewable energy sources. Natural resources can be connected directly to the grid by means of a grid-tied inverter. Another option is to combine renewable generation with local loads to form an independent power system [1].

A nano-grid is defined an aggregation of local small scale generators and loads. The load on a nanogrid is typically less than 20 kW, as in the case of a small rural community or industrial site, and the loads are located within 5 km of the pico sources. The generators are primarily based on clean forms of energy such as fuel cells, solar arrays, and wind turbines. If a nanogrid has sufficient generation and storage, it can operate as an independent power island. However, a nanogrid can be connected to the grid to export excess power and to eliminate the need for energy storage.

Renewable generation, excluding wind power, is currently more expensive than central generation. In the future, however, nanogrids may find a niche in New Zealand's rural power system, where the cost of power is expected to increase due to a deregulated electricity market. Nanogrids may become a viable method of deferring upgrades and providing voltage support to the weak network.

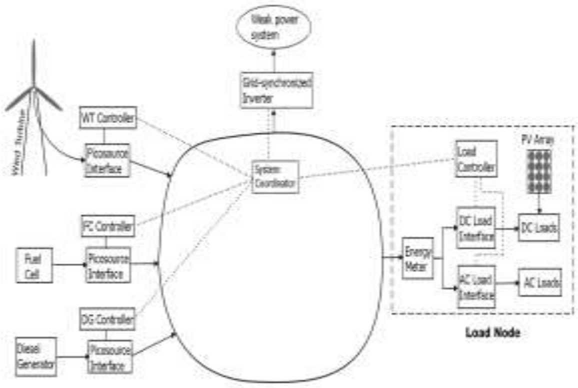


Fig. 1 Structure of an interconnected nanogrid

A nanogrid can be controlled in a decentralized fashion, with each picosource controlling its power output based on local information available at the terminals. Decentralized control is fast and reliable, as it does not require control interconnections, but optimizing the efficiency and overall operation of the nanogrid can be difficult. Another option is central control, which requires a powerful controller and fast communications link to simultaneously control the output of each generator. This strategy allows optimization of the system, but compromises the system's reliability since the system is dependent on a single controller and communication system.

In the nanogrid structure of Fig. 1, three different power converter stages are used to interface the renewable energy source, energy storage unit, and the local ac loads in the system to the dc bus. This paper proposes a structure of the dc nanogrid using switched boost inverter (SBI) [4]–[6] as a power electronic interface. Fig. 2 shows the structure of the proposed SBI based dc nanogrid, and Fig. 3 shows the circuit diagram of the SBI supplying both dc and ac loads.

Fig. 2 shows structure of the proposed SBI based dc nanogrid which has the following advantages when compared to the conventional structure.SBI is a single-stage power converter that can supply both dc (between node VDC and ground) and ac loads (between nodes AO and BO) simultaneously from a single dc input. So, it can realize both the dc-to-dc converter for solar panel and the dc-to-ac converter in a single stage. This decreases size and cost of overall system.

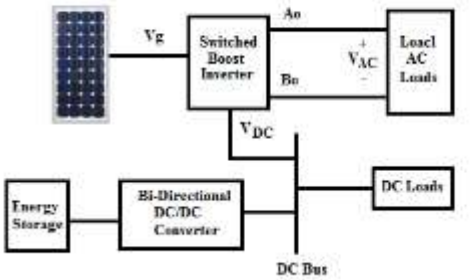


Fig.2. Structure of the proposed SBI-based dc nanogrid.

The output ac voltage of SBI can be either higher or lower than the available source voltage. So, it has wide range of obtainable output voltage for a given source voltage.SBI exhibits better electromagnetic interference (EMI) noise immunity when compared to a traditional voltage source inverter (VSI), as the shoot-through (both switches in one leg of the inverter bridge are turned ON simultaneously) due to EMI noise will not damage the inverter switches [4]. This reduces extra burden on the power converter protection circuit and helps in realization of compact design of the power converter. As the SBI allows shoot-through in the inverter legs, it does not require a dead-time circuit and hence eliminates the need for complex dead-time compensation technologies.

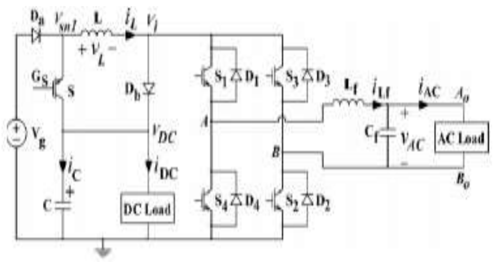


Fig.3. Circuit diagram of SBI supplying both dc and ac loads.

As shown in Fig. 3, the SBI has one active switch (S), two diodes (Da , Db), one inductor (L), and one capacitor (C) connected between voltage source Vg and the inverter bridge. A low-pass LC filter is used at the output of the inverter bridge to filter the switching frequency components in the inverter output voltage vAB. As shown in Fig. 3, the capacitor C (connected between node VDC and ground) of SBI acts as a dc bus for dc loads while the capacitor Cf (connected between nodes AO and BO) of SBI acts as an ac bus for ac loads. The operating principle and pulse width modulation (PWM) control of the SBI.

II. SWITCHED BOOST INVERTER TOPOLOGY

SBI is a single-stage power converter derived from Inverse Watkins Johnson (IWJ) Topology. This topology exhibits properties similar to that of a Z-source inverter (ZSI) with lower number of passive components and more active components. This section presents a review of the approach used to derive the SBI from IWJ topology. A detailed comparison of SBI with a traditional two-stage dc-to-ac conversion system

A. Derivation of SBI from IWJ Topology

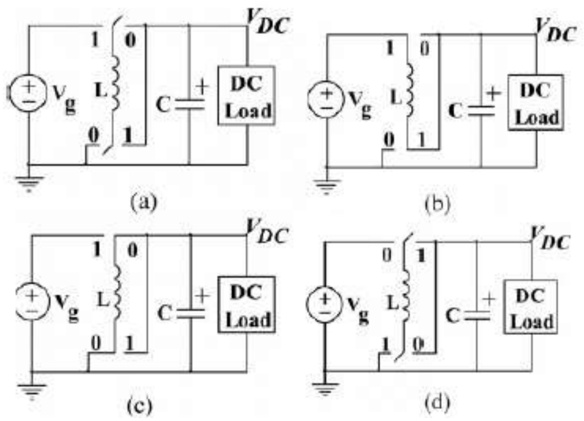


Fig.4. (a) Schematic of IWJ topology. (b) Equivalent circuit of IWJ topology in D·TS interval. (c) Equivalent circuit of IWJ topology in (1 – D)·TS interval. (d) CIWJ topology

The schematic of IWJ converter is shown in Fig. 4(a) and its equivalent circuits in D·TS and (1 – D)·TS intervals of a switching cycle TS are shown in Fig. 4(b) and (c), respectively. As shown in Fig. 4(b), during D·TS interval, the two switches of the converter are in position 1, and inductor L is connected between the input and the output. Similarly, during (1 – D)·TS interval, the switches are in position 0 and the inductor is connected between the output and the ground, as shown in Fig. 4(c). Interchanging the D·TS (position 1), and (1 – D)·TS (position 0) intervals of IWJ converter leads to Fig. 4(d). This configuration is named as the complementary IWJ (CIWJ) topology.

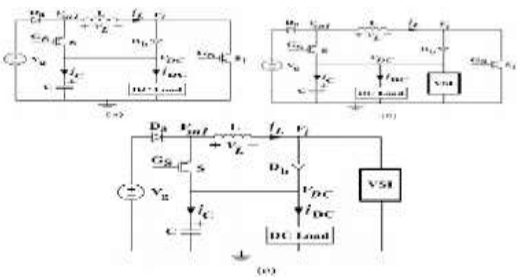


Fig.5. (a) Realization of CIWJ topology using power semiconductor devices.(b) Connection of a VSI across the dc output node VDC of CIWJ topology.(c) Connection of a VSI across the switching terminal Vi of the CIWJ topology

Fig. 5(a) shows the realization of CIWJ topology using power semiconductor devices [4], [5]. The output of this converter is a dc voltage VDC. In order to convert this dc voltage to an ac voltage, one has to use a VSI. This VSI may be directly connected at the output node VDC of CIWJ topology [shown in Fig. 5(b)], which becomes a cascaded connection of a dc–dc converter and a regular VSI. But this combination cannot overcome the general limitations of a traditional VSI [7], [8], viz., 1) dead-time is necessary to prevent the damage of the switches in the event of shoot-through in inverter phase legs, 2) complex dead-time compensation technologies should be used to compensate the waveform distortion caused by dead-time. Fig. 5(c) shows another possible connection of the VSI, in which the inverter bridge is connected across the switch node Vi of the CIWJ topology. Note that this combination requires only controlled switch S apart from the inverter bridge. The switch Si of CIWJ topology can be realized by utilizing the shoot-through state of the inverter bridge. Also, similar to the cascaded connection shown in Fig. 5(b), this circuit can also supply a dc load (at the output of CIWJ) and an ac load (at the output of the inverter bridge) simultaneously from a single dc voltage source Vg. When compared to the cascaded connection shown in Fig. 5(b), the SBI has following advantages:

1) In the event of shoot-through in any phase leg of the inverter bridge, the diode Db is reverse biased and capacitor C is disconnected from the inverter bridge. Now, the current through the circuit is limited by the inductor L. So, similar to ZSI, shoot-through does not damage the switches of the SBI also.
2) As the SBI allows shoot-through, no dead time is needed to protect the converter. Also this circuit exhibits better EMI noise immunity compared to a traditional VSI.
3) Since dead-time is not required, there is no need of extra dead-time compensation technologies to compensate the waveform distortion caused by dead-time.

III. PHOTOVOLTAIC (PV) SYSTEM

A Photovoltaic (PV) system directly converts solar energy into electrical energy. The basic device of a PV system is the PV cell. Cells may be grouped to form arrays. The voltage and current available at the terminals of a PV device may directly feed small loads such as lighting systems and DC motors or connect to a grid by using proper energy conversion devices.

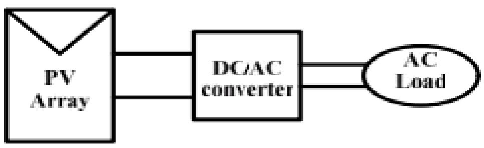


Fig.6. Block diagram representation of Photovoltaic system

This photovoltaic system consists of three main parts which are PV module, balance of system and load. The major balance of system components in this systems are charger, battery and inverter. The Block diagram of the PV system is shown in Fig.6. A photovoltaic cell is basically a semiconductor diode whose p–n junction is exposed to light. Photovoltaic cells are made of several types of semiconductors using different manufacturing processes. The incidence of light on the cell generates charge carriers that originate an electric current if the cell is short circuited.

IV. MATLAB MODELING AND SIMULATION RESULTS

Here the simulation is carried out in different cases
1) Performance of SBI with AC and DC Load Changer.
2) Performance of SBI with an RL and Rectifier load.
3) Operation of SBI with an Isolation Transformer.
4) Operation of SBI with an Isolation Transformer using PV Cell.

Case 1 :(a) Performance of SBI with* a Step Change in *AC Load

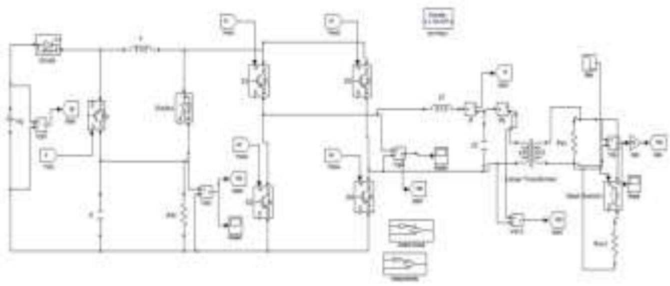


Fig.7 Matlab/Simulink Model of Switched Boost Inverter with a Closed Loop Control System with a Step Change in AC Load.

Fig.7 shows the Matlab/Simulink Model of Switched Boost Inverter with a Step Change in AC Load.

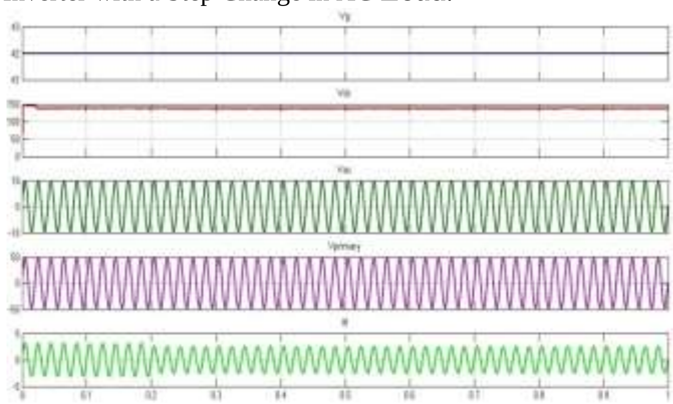


Fig.8 SBI with a Step Change in AC Load, input voltage Vg , dc load voltage VDC , ac output voltage of SBI VAC.

Fig.8 shows the SBI with a Step Change in AC Load, input voltage Vg , dc load voltage VDC , ac output voltage of SBI VAC.

Case 1 :(b) Performance of SBI with **a Step Change in** ***DC Load***

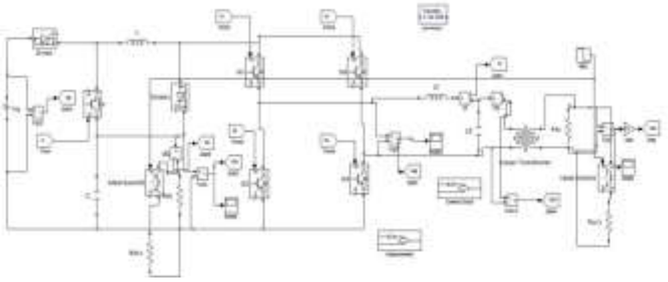


Fig.9 Matlab/Simulink Model of Switched Boost Inverter with a Closed Loop Control System with a Step Change in DC Load.

Fig. 9 shows the Matlab/Simulink Model of Switched Boost Inverter with a Step Change in DC Load.

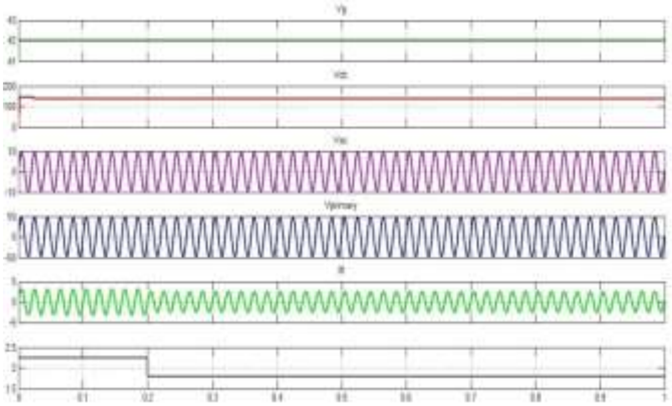


Fig.10 SBI with a Step Change in DC Load, input voltage Vg , dc load voltage VDC , ac output voltage of SBI VAC.

Fig.10 shows the SBI with a Step Change in DC Load, input voltage Vg , dc load voltage VDC , ac output voltage of SBI VAC, and Vpri switch node voltage.

Case 2: **Performance of SBI with an RL and Rectifier load.**

(a) . With RL Load.

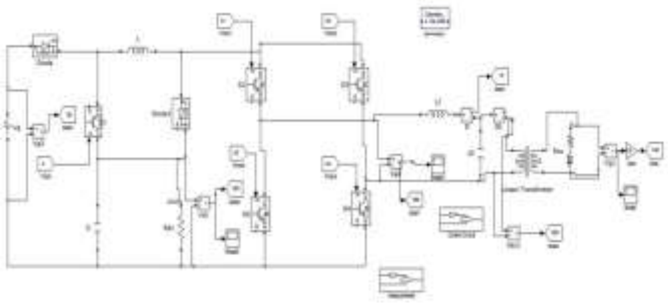
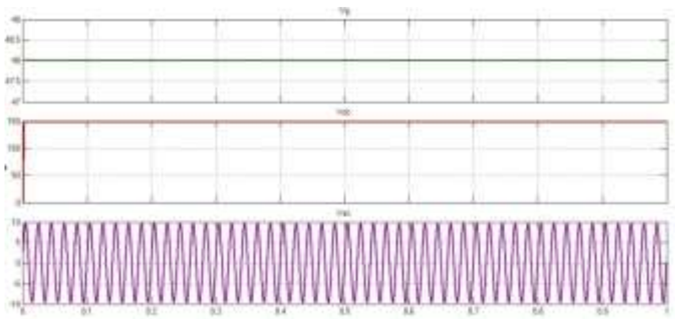
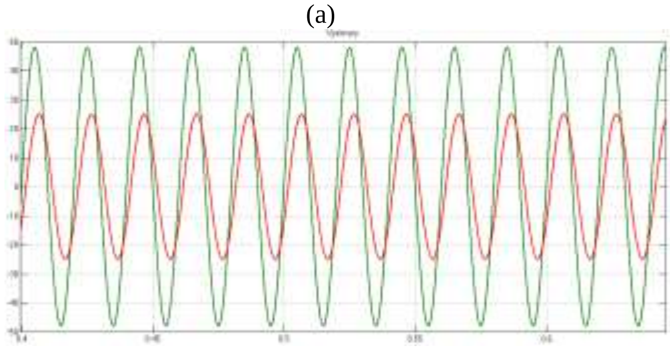


Fig.11 Matlab/Simulink Model of Switched Boost Inverter with a RL Load

Fig.11 shows the Matlab/Simulink Model of Switched Boost Inverter with a RL Load.



(a)



(b)

Fig.12 SBI with a RL Load, (a) Input Voltage (Vg), Output Voltage Vdc), Ac Voltage (Vac) (b) Vac & Iac

Fig.12 shows the operation of SBI with a RL Load, (a) Input Voltage (Vg), Output Voltage Vdc), Ac Voltage (Vac) (b) Vac & Iac.

(b) . With Rectifier Load.

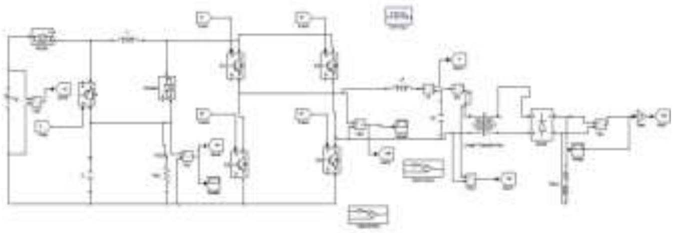
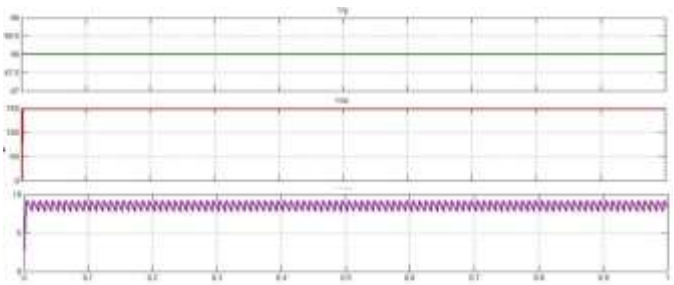
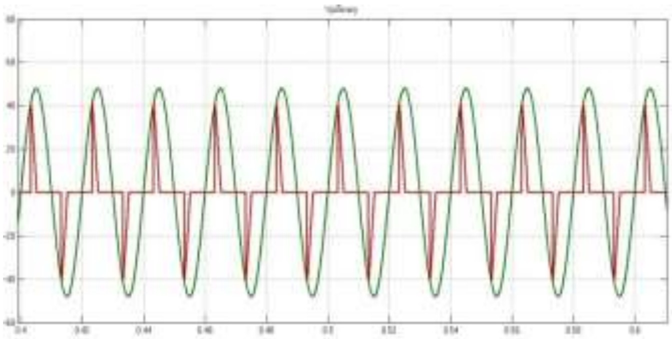


Fig.13 Matlab/Simulink Model of Switched Boost Inverter with a Rectifier Load

Fig.13 shows the Matlab/Simulink Model of Switched Boost Inverter with a Rectifier Load.



(a)



(b)

Fig.14 SBI with a Rectifier Load, (a) Input Voltage (Vg), Output Voltage Vdc), Ac Voltage (Vac) (b) Vac & Iac

Fig.14 shows the operation of SBI with a Rectifier Load, (a) Input Voltage (Vg), Output Voltage Vdc), Ac Voltage (Vac) (b) Vac & Iac.

Case 3: Operation of SBI with an Isolation Transformer.

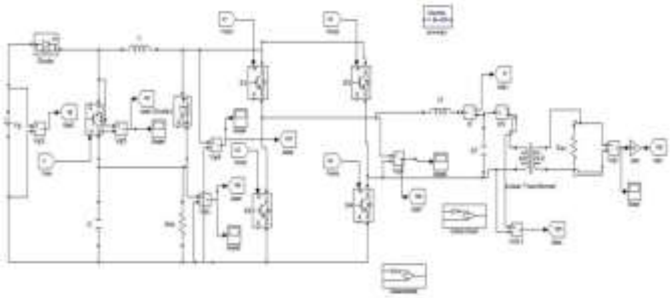


Fig.15 Matlab/Simulink Model of Switched Boost Inverter with an Isolation Transformer.

Fig.15 shows the Matlab/Simulink Model of Switched Boost Inverter with an Isolation Transformer.

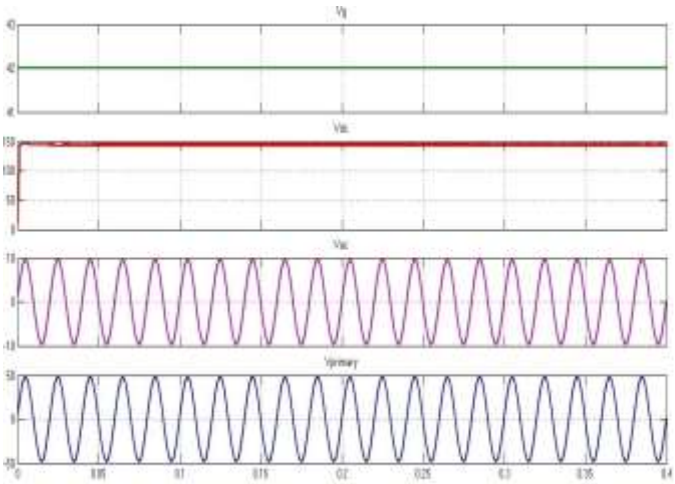


Fig.16 Operation of SBI with an isolation transformer, input voltage Vg , dc load voltage VDC , ac output voltage of SBI VAC , and ac load voltage.

Fig.16 shows the Operation of SBI with an isolation transformer, input voltage *Vg* , dc load voltage VDC , ac output voltage of SBI VAC , and ac load voltage.

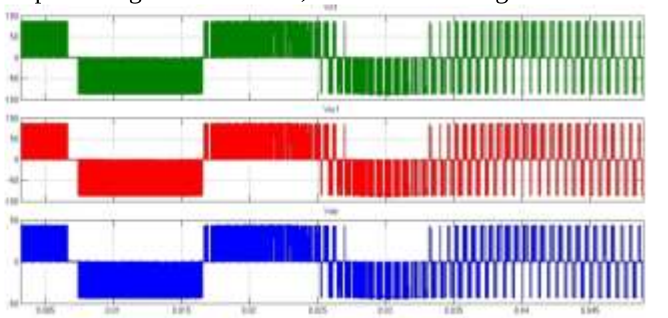


Fig.17 Operation of SBI with an isolation transformer, switch node 1 voltage Vsn1 , input voltage of the inverter bridge Vi, and Output voltage of H-Bridge VAB.

Fig.17 shows the Operation of SBI with an isolation transformer, switch node 1 voltage *V*sn1, input voltage of the inverter bridge *Vi*, and Output voltage of H-Bridge *V*AB.

Case 4: Operation of SBI with an Isolation Transformer using PV Cell.

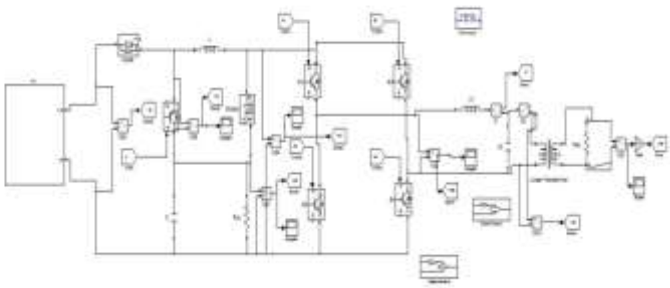


Fig.18 Matlab/Simulink Model of Proposed Switched Boost Inverter with an Isolation Transformer.

Fig.18 shows the Matlab/Simulink Model of Switched Boost Inverter with an Isolation Transformer using PV Cell.

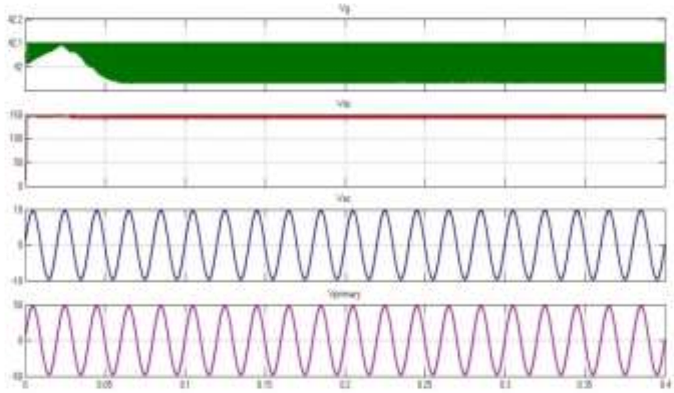


Fig.19 Steady-state operation of SBI with an isolation transformer with PV Model, input voltage Vg , dc load voltage VDC , ac output voltage of SBI VAC , and ac load voltage

Fig.19 shows the Steady-state operation of SBI with an isolation transformer with PV Model, input voltage Vg , dc load voltage VDC , ac output voltage of SBI VAC , and ac load voltage.

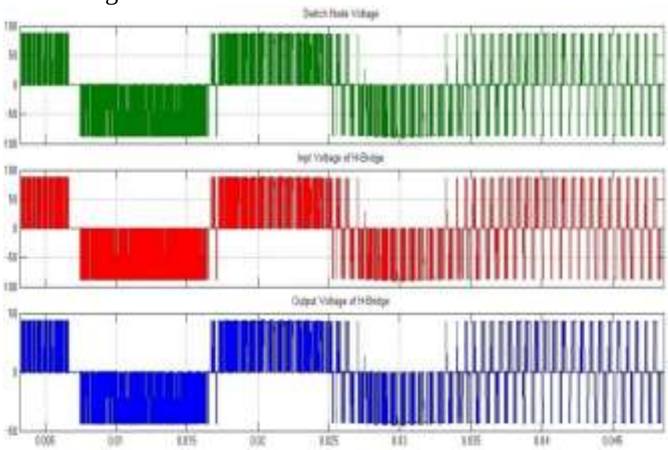


Fig.20 Steady-state operation of SBI with an isolation transformer, switch node 1 voltage Vsn1 , input voltage of the inverter bridge Vi, and Output voltage of H-Bridge VAB.

Fig.20 shows the Steady-state operation of SBI with an isolation transformer, switch node 1 voltage *V*sn1, input voltage of the inverter bridge *Vi*, and Output voltage of H-Bridge *V*AB.

V. CONCLUSION

This paper presents a novel power electronic interface called switched boost inverter (SBI) for dc nanogrid applications with the combination of Photovoltaic Cell and Fuel cell. It is supplied for both dc and ac loads simultaneously from a single dc input. It is also proven that the SBI can generate an ac output voltage that is either higher or lower than the available source voltage. This paper also describes the advantages and limitations of SBI when compared to the ZSI and the traditional two stage dc-to-ac conversion system. The performance of SBI has been tested using simulation with an isolation transformer and also with three different types of ac loads: *R*, *RL*, and nonlinear loads. It can be concluded from the simulation results that the control strategy of SBI shows excellent performance during steady state as well as during a step change in either dc or ac load in the system. These results confirm the suitability of SBI and its closed-loop control strategy for dc nanogrid applications with PV Source.

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