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RESEARCH ARTICLE

SWITCHED BOOST INVERTER FOR STANDALONE DC NANOGRID APPLICATIONS IN POWER SYSTEMS

[1]Mekala Santhosh Reddy and [2,*]Dr. V. Balakrishna Reddy

[1]Project Trainee, Unisoft Application Pvt Ltd, Hyderabad, Telangana State, India
[2]Department of EEE, Vijay Rural Engg College, Nizamabad, Telangana State, India

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ABSTRACT

Switched boost inverter (SBI) is a single-stage power converter derived from Inverse Watkins Johnson topology. Unlike the traditional buck-type voltage source inverter (VSI), 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. Another advantage of SBI is that it can supply both dc and ac loads simultaneously from a single dc input. These features make the SBI suitable for dc nanogrid applications. In this paper, the SBI is proposed as a power electronic interface in dc nanogrid. The structure and advantages of the proposed SBI-based nanogrid are discussed in detail. 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.

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INTRODUCTION

General

Normally in India, Grid system is very traditional (old) one. So the reliability and efficiency is low. Power Gird system is Generation Transmission and Distribution. It is like one way communication. It inter-links one to one. This may lead to affect the system, when the fault occurs in any of the system line. Power transmission is limited. Information technology between the power systems is very poor. We can’t create a flexible electric power system because of absences of intelligent and co-operating resources. This poor power system will leads to more power losses. And we can’t penetrate non-traditional power generation such as Renewable energy system into our power system.

Scope of the paper

This paper presents that the emerging trend of smart grids. Smart grid is nothing but normal grid but it inter link grid with many micro grid.

Corresponding author: Dr. V. Balakrishna Reddy,
Department of EEE, Vijay Rural Engg College, Nizamabad, Telangana State, India.

And also it is like two way communication. How it is possible to get a two way communication? This is possible by connecting more number of micro grids with it. So, now clear that we are using more number of generating unit, we have more reliable control and information technology is used to improve the grid’s efficiency.

Existing System

In the traditional grid has low efficiency and one way communication. Generating stations are very minimum and long transmission is lead to more power losses. Normal dc source can be boosted and inverted for AC load. Many drawbacks are discussed in above paragraph itself. So let us see the existing technique which is under process in power system.

Existing Systems Technique

A dc NANOGRID consisting of a solar panel as an energy source, a storage unit, and some dc and local ac loads. The solar panel is associated with a series blocking diode *DS* to avoid reverse power conduction. As the dynamic behaviors of all the different units of NANOGRID are not uniform, they are interfaced to a common dc bus using power electronic converters. In this the NANOGRID has 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.

Proposed system

This proposes a structure of the dc NANOGRID using switched boost inverter (SBI) as a power electronic interface. The structure of the proposed SBI-based dc NANOGRID shows the SBI supplying both dc and ac loads. The operating principle and pulse width modulation (PWM) control of the SBI have been explained.

Proposed system technique

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 *v*AB. The capacitor *C* (connected between node *V*DC 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.

Paper Description

General

DCNANOGRID is a low-power dc distribution system suitable for residential power applications. The average load demand in the nanogrid is generally met by the local renewable energy sources like solar, wind, etc. An energy storage unit is also required in the nanogrid to ensure uninterruptible power supply to the critical loads and to maintain power balance in the nanogrid. The solar panel is associated with a series blocking diode *DS* to avoid reverse power conduction. As the dynamic behaviors of all the different units of nanogrid are not uniform, they are interfaced to a common dc bus using power electronic converters. As per the consumer preference, each dc load in the nanogrid also has its own power electronic interface which is not for simplicity.

Modules Name

- Switched boost inverter
- Nanogrid
- Synchronous reference frame control
- PV system
- SPWM
- THD
- Simulation Results
- Hardware Theory

Module Description

Switched Boost Inverter

Z-source inverter (ZSI) uses an L-C impedance network between the source and the voltage source inverter (VSI). It has the property of stepping down or stepping up the input voltage, as a result, the output can be either higher or lower than the input voltage as per requirement. This topology also possesses robust Electromagnetic Interference (EMI) noise immunity, which is achieved by allowing shoot-through of the inverter leg switches. This impedance network consists of two inductors and two capacitors, which causes significant increase in the size of the power converter. Moreover, for stable operation of the converter, this impedance network has to be perfectly symmetrical which is difficult to achieve in practice. In this paper, an alternative implementation of the ZSI is derived. The resulting topology is called Switched Boost Inverter (SBI). It has half the number of passive components when compared to ZSI while retaining its primary operational advantages. This paper explains the steady state operation and small signal behavior of the switched boost inverter. This paper proposes an inverter circuit based on Inverse Watkins-Johnson topology that can achieve similar advantages as that of a ZSI.

Nanogrid

The nanogrid employs power electronic interface circuits to connect the generators and loads to the nanogrid, and to link the nanogrid to a weak power system. A step-up converter, or picosource interface, connects the picosources to the nanogrid. Picosources typically produce a low DC voltage output while the nanogrid operates at a higher voltage to achieve high transmission efficiency. Similarly, a step-down converter allows AC and DC consumer loads to draw power from the nanogrid. The nanogrid employs a decentralised control strategy to control the power flow in the nanogrid. The power balance is achieved through independent control of each picosource interface; no control interconnections are required.

Synchronous Reference Frame Control

Current regulators for AC inverters are commonly categorized as hysteresis, linear PI, or deadbeat predictive regulators, with a further sub-classification into stationary ABC frame and synchronous d-q frame implementations. Synchronous frame regulators are generally accepted to have a better performance than stationary frame regulators, as they operate on DC quantities and hence can eliminate steady-state errors. This paper establishes a theoretical connection between these two classes of regulators and proposes a new type of stationary frame regulator, the P+Resonant regulator, which achieves the same transient and steady-state performance as a synchronous frame PI regulator. The new regulator is applicable to both single-phase and three phase inverters.

PV System

The word “photovoltaic” combines two terms – “photo” means light and “voltaic” means voltage. A photovoltaic system in this discussion uses photovoltaic cells to directly convert sunlight into electricity. Photovoltaic power generation employs solar panels composed of a number of solar cells containing a photovoltaic material. Solar photovoltaic is a sustainable energy source where 100 countries are utilizing it. Solar photovoltaics is now, after hydro and wind power, the third most important renewable energy source in terms of globally installed capacity. Installations may be groundmounted or built into the roof or walls of a building. (either building-integrated photovoltaics or simply rooftop)

Spwm

SPWM technique is based on classical SPWM technique with carriers and reference sine waveform. Only difference between them is, in digital SPWM a sine table consisting of values of sine waveform sampled at certain frequency is used. As result reference wave form in digital SPWM represents a sample and hold wave form of sine wave form.

Output stays high as long as the command is greater than the carrier. Pulse-width modulation (PWM), as it applies to motor control, is a way of delivering energy through a succession of pulses rather than a continuously varying (analog) signal. By increasing or decreasing pulse width, the controller regulates energy flow to the motor shaft. The motor's own inductance acts like a filter, storing energy during the "on" cycle while releasing it at a rate corresponding to the input or reference signal. In other words, energy flows into the load not so much the switching frequency, but at the reference frequency.

THD

Total harmonic distortion (THD) is a complex and often confusing concept to grasp. However, when broken down into the basic definitions of harmonics and distortion, it becomes much easier to understand. Now imagine that this load is going to take on one of two basic types: linear or nonlinear. The type of load is going to affect the power quality of the system. This is due to the current draw of each type of load. Linear loads draw current that is sinusoidal in nature so they generally do not distort the waveform. Most household appliances are categorized as linear loads. Non-linear loads, however, can draw current that is not perfectly sinusoidal. Since the current waveform deviates from a sine wave, voltage waveform distortions are created. Thus waveform distortions can drastically alter the shape of the sinusoid.

RESULTS

Techniques Used

- Switched Boost Inverter:
- Sinusoidal PWM

Techniques Description

1 Derivation of SBI From IWJ Topology

The schematic of IWJ converter its equivalent circuits in $D{\cdot}TS$ and $(1 - D){\cdot}TS$ intervals of a switching cycle TS, respectively. During $D{\cdot}TS$ interval, the two switches of the converter are in position 1, and inductor L is connected between the input and the output. Similarly, during $(1 - D){\cdot}TS$ 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 $D{\cdot}TS$ (position 1), and $(1 - D){\cdot}TS$ (position 0) intervals of IWJ converter. This configuration is named as the complementary IWJ (CIWJ) topology. Note that this interchange has no impact on the states of the converter. However, as far as implementation is concerned, this will imply that the controlled switch and diode of CIWJ and IWJ are interchanged.

The output of this converter is a dc voltage V_{DC}. 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 V_{DC} of CIWJ topology, 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, 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. Another possible connection of the VSI, in which the inverter bridge is connected across the switch node V_i of the CIWJ topology. Note that this combination requires only controlled switch S apart from the inverter bridge. The switch S_i of CIWJ topology can be realized by utilizing the shoot-through state of the inverter bridge. Also, similar to the cascaded connection, 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 V_g. The circuit is named as SBI topology.

Note that it is not a direct cascade connection of CIWJ topology and VSI, as the inverter bridge is connected at a switch node of CIWJ converter but not at its output terminal. When compared to the cascaded connection, the SBI has following advantages:

1) In the event of shoot-through in any phase leg of the inverter bridge, the diode D_b 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. Note that a ZSI also exhibits similar advantages of SBI mentioned above. But the SBI achieves these properties with lower number of passive components and more active components compared to ZSI. This is because the impedance network of ZSI uses two inductors, two capacitors, and a diode apart from the inverter bridge, while the SBI requires only one inductor, one capacitor, a controlled switch, and two diodes. The reduction in number of passive components leads to the reduced size of the power converter stage. Also ZSI requires passive components with high consistency which is not the case with SBI. Another major advantage of SBI when compared to ZSI is that it can supply both dc and ac loads simultaneously from a single dc voltage source. However, the limitation of SBI is that its peak inverter input voltage is only $(1 - D)$ times that of ZSI,

where *D* is the shoot-through duty ratio of the inverter bridge. A more detailed quantitative comparison of SBI and ZSI.

2 Sinusoidal PWM

In multiple-pulse modulation, all pulses are the same width. Vary the pulse width according to the amplitude of a sine wave evaluated at the center of the same pulse. In Sine-PWM inverter the widths of the pole-voltage pulses, over the output cycle, vary in a sinusoidal manner. The scheme, in its simplified form, involves comparison of a high frequency triangular carrier voltage with a sinusoidal modulating signal that represents the desired fundamental component of the pole voltage waveform. The peak magnitude of the modulating signal should remain limited to the peak magnitude of the carrier signal. The comparator output is then used to control the high side and low side switches of the particular pole. Fig. 37.1 shows an op-amp based comparator output along with representative sinusoidal and triangular signals as inputs. In the comparator shown in Fig. 37.1, the triangular and sinusoidal signals are fed to the inverting and the non-inverting input terminals respectively and the comparator output magnitudes for high and low levels are assumed to be $+V_{CC}$ and $-V_{CC}$.

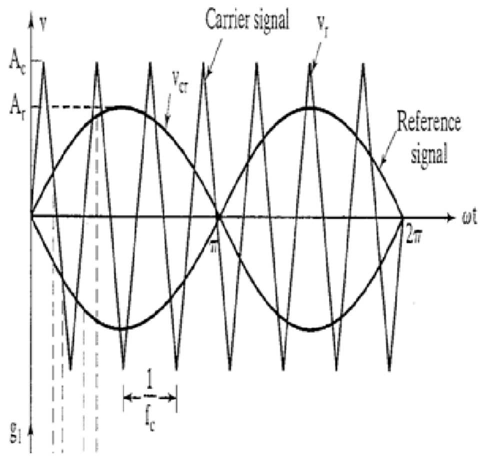


Fig. 1. Modulation Index

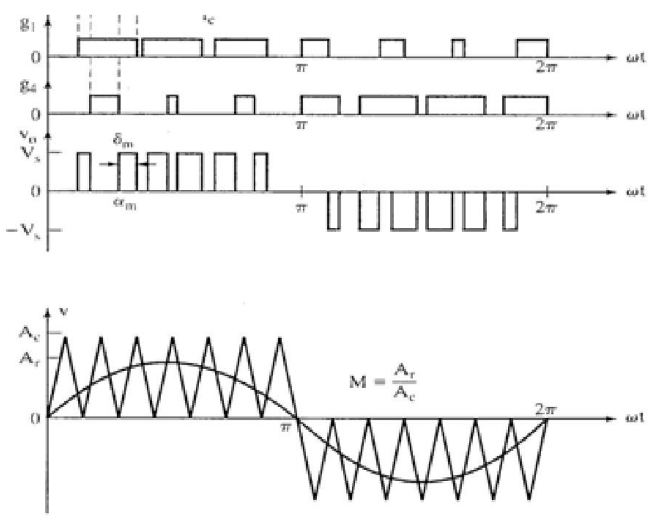


Fig. 2. Pole Voltage Waveform with Sinusoidal Modulating Signal

In the previous section a pure dc modulating signal was considered. Let now a slowly varying sinusoidal voltage, with the following constraints, be considered as the modulating signal:

1. The peak magnitude of the sinusoidal signal is less than or equal to the peak magnitude of the carrier signal. This ensures that the instantaneous magnitude of the modulating signal never exceeds the peak magnitude of the carrier signal.
2. The frequency of the modulating signal is several orders lower than the frequency of the carrier signal. A typical figure will be 50 Hz for the modulating signal and 20 Kilohertz for the carrier signal. Under such high frequency ratios, the magnitude of modulating signal will be virtually constant over any particular carrier-signal time period.

Because of the above assumptions some results of the previous section, where a pure dc modulating signal was considered, may be used. Since the slowly varying modulating signal is virtually constant over a high frequency carrier time period, the mean magnitude of the inverter pole voltage averaged over a carrier time period will be proportional to the mean magnitude of the modulating signal. Thus the discretely averaged magnitude of pole voltage (averaged over successive high frequency carrier time period) is similar to the modulating signal. The pole voltage waveform thus has a low frequency component whose instantaneous magnitude is proportional to the modulating signal (also implying that they will have same frequency and will be in-phase). Apart from this low frequency component the pole voltage will also have high frequency harmonic voltages.

3 Simulation Design without Modulation

A simulation design modulation technique as shown in Fig. 3 is implemented in MATLAB SIMULINK with the help of pulse generators Sinusoidal PWM is generated (Fig. 4). A modified circuit of the system ie Closed switched Boost inverter is also designed which is shown in Fig.3.

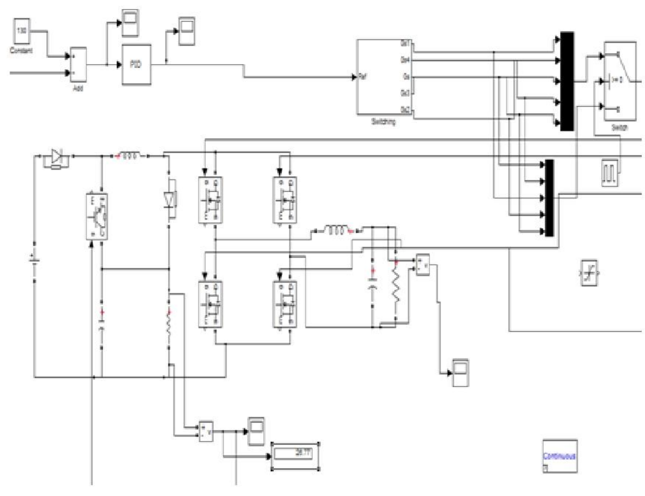


Fig. 3. Proposed switched boost Inverter

Modulation Technique

Dead-Time Requirement: A shoot-through event in the inverter bridge of the two-stage conversion system damages the power converter stage, as well as the dc loads connected to the dc bus of the nanogrid. So a dead-time circuit is necessary to minimize the occurrence of shoot-through events in this system

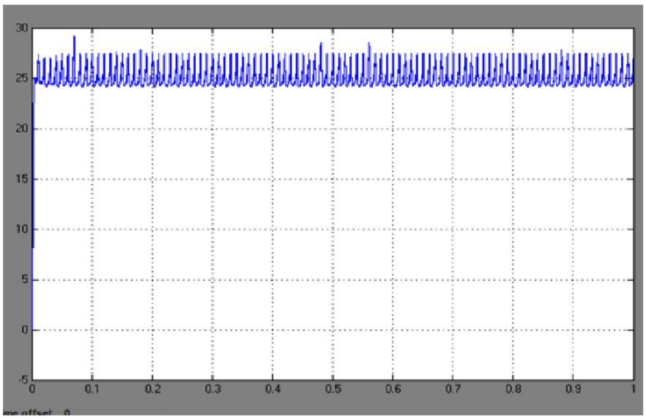


Fig. 4. Output Voltage Waveform

Moreover, to compensate the waveform distortion caused by dead-time, one has to use the complex dead-time compensation technologies. This is not the case with SBI, as it allows shoot-through in the inverter phase legs. So the use of SBI eliminates the need for a dead-time circuit as well as the requirement of dead-time compensation technologies.

2) Reliability and EMI Noise Immunity: Even with a dead time circuit, the probability of a shoot-through event cannot be eliminated completely because an EMI noise can also cause shoot-through in the inverter phase legs.With the use of SBI, the shoot-through event does not damage the switches of the power converter. So, SBI exhibits better EMI noise immunity and hence has better reliability compared to the two-stage conversion system.

3) Extreme Duty Cycle Operation: At the extreme duty ratio operation (e.g., for $D \geq 0.75$) of a conventional boost converter, the inductor L is charged over a longer time duration in the switching cycle, and very small time interval is

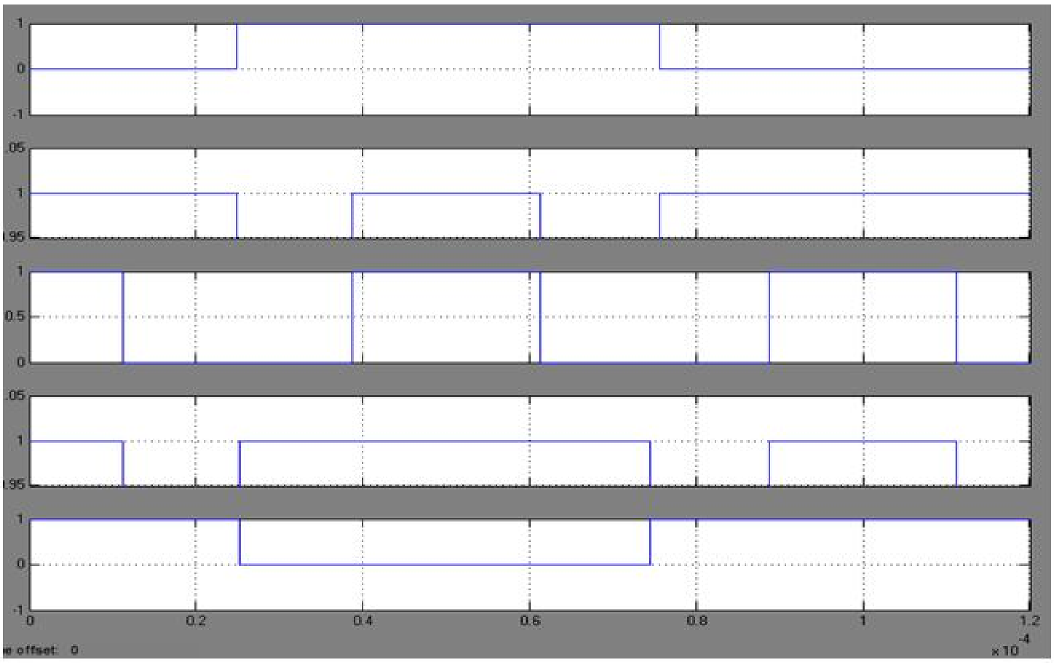
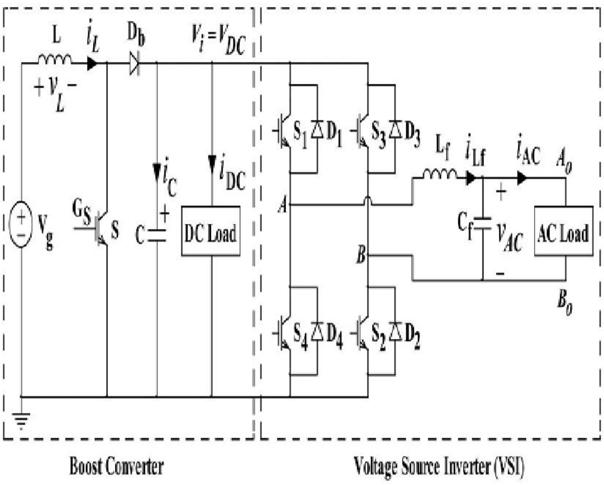


Fig.5. Switching Waveform



left to discharge the inductor through the output diode Db . So this diode should sustain a short pulse width current with relatively high amplitude. Also, this causes severe diode reverse recovery current and increases the EMI noise levels in the converter. This also imposes a limit on the switching frequency of the boost converter and thus increases the size of the passive components used in the two-stage conversion system. In case of SBI, the maximum shoot-through duty ratio is always limited to 0.5 for a positive dc bus voltage V_{DC}. So, even when the converter operates at the point of maximum conversion ratio, the conduction time of the diodes D_a, D_b of SBI is approximately equal to 50% of the switching time period, which alleviates the problems due to extreme duty ratio operation of a boost converter. So, SBI can operate at relatively higher switching frequencies compared to the traditional two stage conversion system. This also decreases the size of passive components used in the power converter.

4) Voltage Stress of Switching Devices: Compares the voltage stress of the semiconductor devices used in the SBI and the two-stage conversion system. From this table, it can be observed that the switch "S" has less voltage stress (VDC – V_g) in case of SBI. For all other devices, the voltage stress is same for both SBI and the two-stage conversion system.

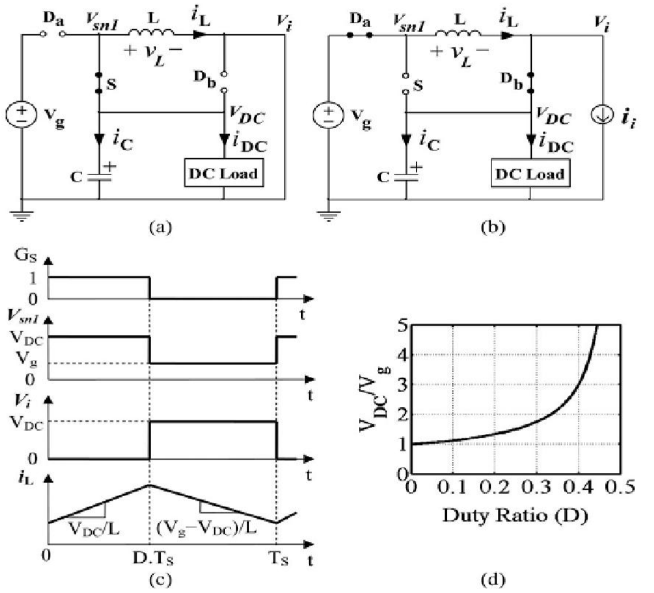
5) Maximum Conversion Ratio: The maximum conversion ratio (VDC/V_g) of a practical boost converter cannot exceed 3.0 (approximately), due to the effects of various non idealities such as DCR/ESR of the passive components, on-state voltage drops of the semiconductor devices, etc. This value may slightly vary depending on the actual values of non ideal elements present in the converter. Similarly, the rms ac output voltage (v_{AC} (rms)) of a single-phase inverter using sinusoidal PWM cannot exceed 1√2 times the dc link voltage (VDC) in the linear modulation range (0 < M < 1), for a low distortion sine wave output. So the maximum overall rms ac-to-dc conversion ratio of two-stage conversion system is approximately 2.12. This value may still decrease if the effects of non idealities in VSI are taken into consideration

6) Number of Control Variables: Similar to a two-stage conversion system, the SBI also has two control variables: Shoot through duty ratio (*D*) and the modulation index (*M*).The dc bus voltage *V*DC is controlled by *D*, while ac output voltage of the converter is controlled by *M*. However, similar to ZSI, the value one of these two control variables decides the upper limit of the second control variable of SBI. The mathematical relation between *D* and *M* depends on the control technique used. Note that, as mentioned above, it is possible to extend most of the PWM control techniques of ZSI to control the SBI also.

7) Number of Devices*:* The SBI requires five active switches, six diodes, two inductors, and two capacitors for its realization. The two-stage conversion system shown in Fig. 6 uses only one diode (D_a) less compared to the SBI. However, in a dc nanogrid, the input comes from a renewable energy source, e.g., solar panel or fuel cell, which should always be associated with a series diode to block the reverse power flow. So the diode D_a of SBI can be a part of the renewable energy source which eliminates the need for an external diode. Thus, the number of devices in both converters is same.

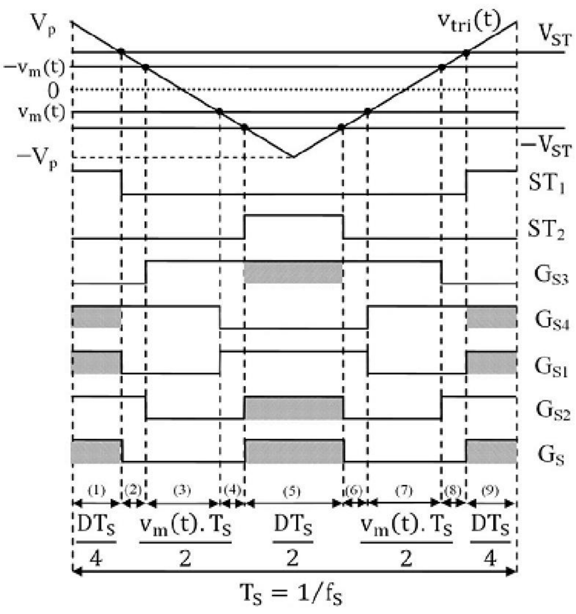
Steady-State Analysis of SBI

The circuit diagram of SBI supplying both dc and ac loads is the equivalent circuits of SBI during the shoot-through interval D·TS and non-shoot through interval (1 – D)·TS of the inverter bridge, respectively. During D·TS interval, the inverter is in shoot-through zero state and switch S is turned ON. The diodes D_a and D_b are reverse biased as $V_{DC} > V_g$. In this interval, capacitor C charges the inductor L through switch S and the inverter bridge. So, the inductor current equals the capacitor discharging current minus the dc load current. During (1 – D) ·TS interval, the inverter is in non-shoot through state and the switch S is turned OFF. The inverter bridge is represented by a current source in this interval as shown in the equivalent circuit of Fig. 7(b). Now, the voltage source Vg and inductor L together supply power to the dc load, inverter, and the capacitor through diodes D_a and D_b. The inductor current in this interval equals the capacitor charging current added to the inverter input current and the dc load current. Note that the inductor current is assumed to be sufficient enough for the continuous conduction of the diodes *Da* , *Db* for the entire interval (1 – *D*)·*TS*



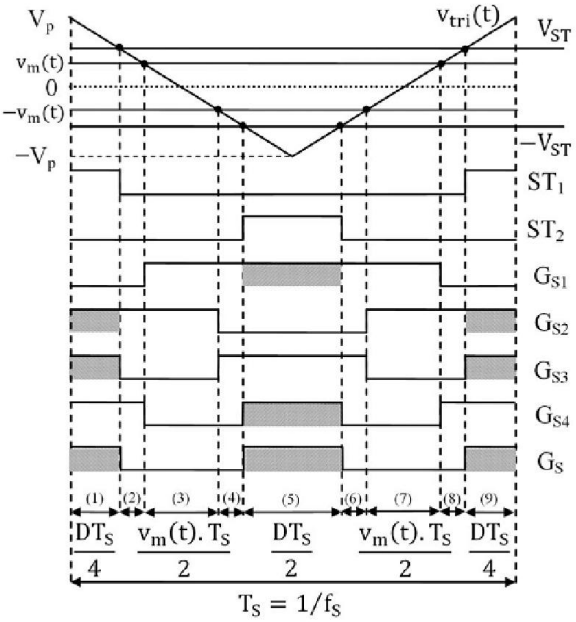
PWM Control of SBI

The SBI utilizes the shoot-through interval of the H-bridge to invoke the boost operation. So, the traditional PWM techniques of VSI have to be modified to incorporate the shoot-through state, so that they are suitable for SBI.



A PWM scheme for SBI is developed based on the traditional sine-triangle PWM with unipolar voltage switching. During positive half cycle of $v_{m(t)}$ ($v_{m(t)}$ > 0), the gate control signals

G_{S1} and G_{S2} are generated by comparing the sinusoidal modulation signals $v_{m(t)}$, and $-v_{m(t)}$ with a high-frequency triangular carrier $v_{tri(t)}$ of amplitude V_p . The frequency f_S of the carrier signal is chosen such that f_S _f_O . Therefore, $v_{m(t)}$ is assumed to be nearly constant. The signals S_{T1} and S_{T2} are generated by comparing $v_{tri(t)}$ with two constant voltages V_{ST} and $-V_{ST}$, respectively. The purpose of these two signals is to insert the required shoot-through interval $D{\cdot}TS$ in the PWM signals of the inverter bridge.



During positive half cycle of $v_{m(t)}$, the shoot-through signals S_{T1}, S_{T2} are logically added to G_{S2} , G_{S1} , respectively, while in negative half cycle of $v_{m(t)}$, these signals are logically added toG_{S4}, G_{S3}, respectively. This takes care that all four switches of the inverter bridge equally participate in generating the shoot-through interval.

Expected Input and Expected Output

Given I/P & Expected O/P

Simulation

- V_{in} = 24V DC from Solar panel
- Vo1 = 48Vac_rms, Vo2=130Vdc

Hardware

- Vin=12VDC FROM PANEL
- Vo=200V DC & 230V AC

Advantages

- SBI is a single-stage power converter.
- Decreases size and cost of overall system.
- SBI can be either higher or lower than the available source voltage.
- SBI exhibits better electromagnetic interference (EMI) noise immunity.
- Eliminates the complex dead-time compensation technologies

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