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Fuzzy Controlled Switched Boost Inverter for Nano-grid Applications

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Abstract: The constantly growing need for more electric power as a result of a global technological development on one side, but vulnerable environment on the other, definitely influences the way how the electricity will be produced, transmitted, distributed and utilized in the future. This will inevitably put the existing electric power system under a serious revision in order to increase efficiency, reliability and response to the end user, but in the same time offer more controllability, higher safety and user-friendly access. Power electronics, along with an advanced energy management provides an excellent solution to this problem. 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. This paper presents a structure of the SBI-based dc nanogrid and its advantages compared to the conventional structure. This paper also describes the steady-state and small signal analysis of SBI supplying both dc and ac loads along with its PWM control technique. Also, a closed-loop control strategy of SBI that regulates both the dc and ac bus voltages of SBI to their respective reference values has been given. Finally the proposed control topology can be implemented for fuzzy logic control technique by using MATLAB/SIMULINK software for optimal performance of the system.

Keywords: Switched Boost Inverter, Nano-grid, Synchronous Reference Frame Based Theory.

I. INTRODUCTION

Nanogrid architectures are greatly incorporated in the modern power system. In this system there is DC as well as AC loads supplied by different kinds of energy sources using efficient power electronic converters [2]. Fig.1 shows the schematic of the SBI based DC grid in which single PV panel (DC source) supplies both AC and DC loads. Fig. 1 shows the conventional architecture in which DC and AC load supplied by separate DC-DC converter and DC-AC converter from a single DC source respectively. This overall system decreases size and cost of the system. 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. The SBI is a single input, two-output (one dc output and one ac output) power converter derived from IWJ converter and a VSI. Similar to the traditional two stage dc-to-ac conversion system, the SBI can also generate an ac output voltage that is either greater or less than the input dc voltage. However, the SBI has certain advantages when compared to the two stage conversion system shown which are discussed below:

1. 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 grid. So a dead-time circuit is necessary to minimize the occurrence of shoot-through events in this system.

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.

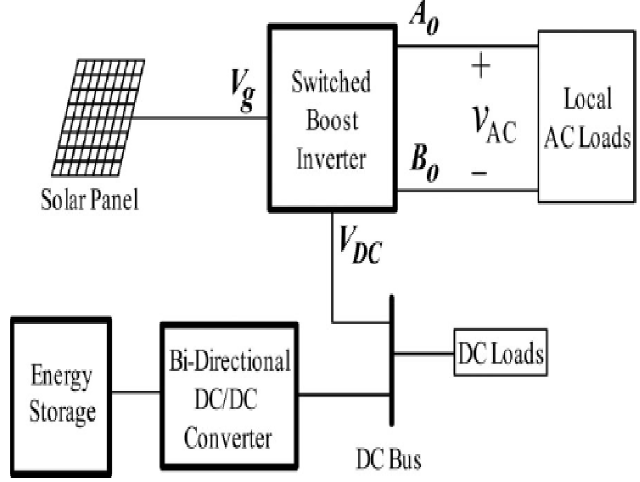


Fig.1. Structure of the proposed DC grid.

II. SWITCHED BOOST INVERTER

Switched boost inverter **(**SBI) is a single stage power converter that can supply both DC and AC loads (between nodes 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. 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. 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 This project presents a structure of the SBI-based dc grid and its advantages compared to the conventional structure This paper also describes the steady-state and small signal analysis of SBI supplying both dc and ac loads along with its PWM control technique as shown in Fig.2. Finally the proposed topology is applied to fuzzy logic control system for optimal performance of the system.

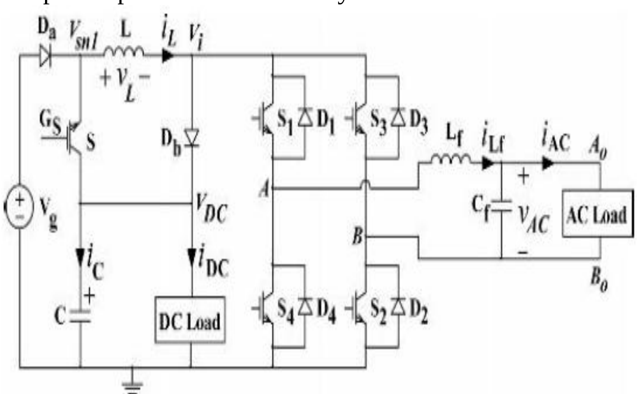
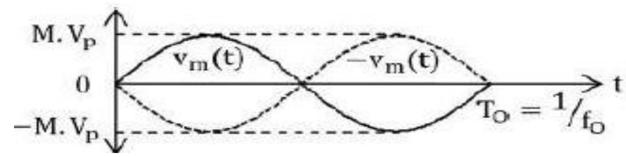


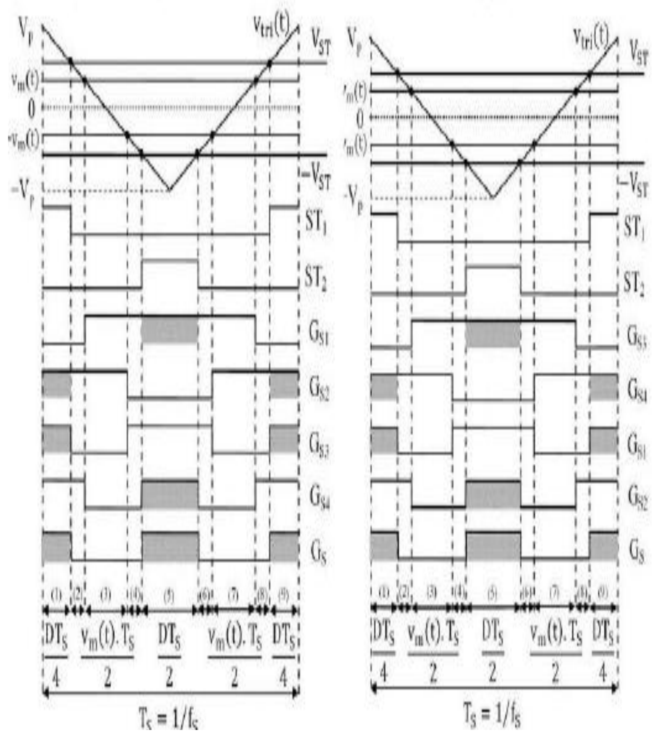
Fig.2. Circuit diagram of SBI supplying both dc and ac loads.

III. 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. In a PWM scheme for SBI is developed based on the traditional sine-triangle PWM with unipolar voltage switching This technique has been illustrated in Fig.3 during positive and negative half cycles of the sinusoidal modulation signal vm(t) shown in Fig. 3(a) The frequency f_S of the carrier signal is chosen such that f_S _f_O . Therefore, vm(t) is assumed to be nearly constant in Fig. 3.(b). The signals S_{T1} and S_{T2} are generated by comparing vtri(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·TS in the PWM signals of the inverter bridge.



(a)



(b)

Fig.3. PWM control of SBI ,(a) Sinusoidal Modulation Signals v_m(t)and -v_m(t), (b)Generation of gate control signals for SBI when v_m(t)<0 and v_m(t)>0.

IV. SWITCHED BOOST INVERTER VS TRADITIONAL TWO-STAGE DC-TO-AC CONVERSION SYSTEM

In the previous section, it is shown that the SBI is a single input, two-output (one dc output and one ac output) power converter derived from IWJ converter and a VSI. Similar to the traditional two-stage dc-to-ac conversion system shown in Fig. 4.

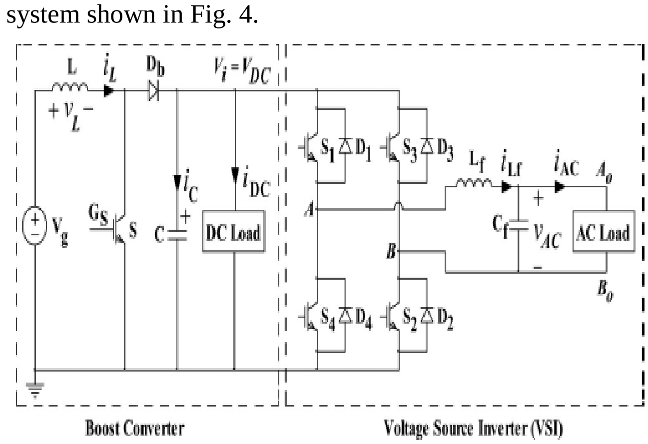


Fig.4 Traditional two-stage dc-ac conversion system.

The SBI can also generate an ac output voltage that is either greater or less than the input dc voltage. However, the SBI has certain advantages and limitations when compared to the two stage conversion system shown in Fig. 4, which is discussed below:

A. 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 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 VDC. So, even when the converter operates at the point of maximum conversion ratio, the conduction time of the diodes Da , Db 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.

TABLE I: Voltage Stress Comparison of SBI and Two stage Conversion System

Converter	Voltage stress across the device				
	S	S_1, S_2, S_3, S_4	D_a	D_b	D_1, D_2, D_3, D_4
SBI (Fig. 3)	$V_{DC} - V_g$	V_{DC}	V_g - V_{DC}	V_{DC}	V_{DC}
Two-stage conversion system (Fig. 6)	V_{DC}	V_{DC}	-	V_{DC}	V_{DC}

B. Voltage Stress of Switching Devices

Table I compares the voltage stress of the semiconductor devices used in the SBI and the two-stage conversion system shown in Fig. 6. From this table, it can be observed that the switch “S” has less voltage stress ($V_{DC} - V_g$) in case of SBI. For all other devices, the voltage stress is same for both SBI and the two-stage conversion system.

C. Maximum Conversion Ratio

The maximum conversion ratio (V_{DC}/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 $1/\sqrt{2}$ times the dc link voltage (v_{DC}) in the The rms ac-to-dc conversion ratio of the two-stage conversion ratio may be increased slightly by using semiconductor devices with very low forward voltage drops and which is comparable to that of a two-stage conversion system.

D. 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 (vDC) 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.

E. Number of Devices

As shown in Fig.3, 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 grid, 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.

V. FUZZY CONTROLLER

Fig.5 shows the internal structure of the control circuit. The control scheme consists of Fuzzy controller, limiter, and three phase sine wave generator for reference current generation and generation of switching signals. The peak value of reference currents is estimated by regulating the DC link voltage. The actual capacitor voltage is compared with a set reference value. The error signal is then processed through a Fuzzy controller, which contributes to zero steady error in tracking the reference current signal. A fuzzy controller converts a linguistic control strategy into an automatic control strategy, and fuzzy rules are constructed by expert experience or knowledge database. Firstly, input voltage V_{dc} and the input reference voltage $V_{dc\text{-}ref}$ have been placed of the angular velocity to be the input variables of the fuzzy logic controller. Then the output variable of the fuzzy logic controller is presented by the control Current Imax. To convert these numerical variables into linguistic variables, the following seven fuzzy levels or sets are chosen as: NB (negative big), NM (negative medium), NS (negative small), ZE (zero), PS (positive small), PM (positive medium), and PB (positive big) as shown in Fig.10. The fuzzy controller is characterized as follows:

- Seven fuzzy sets for each input and output;
- Fuzzification using continuous universe of discourse;
- Implication using Mamdani's ‘min’ operator;
- De-fuzzification using the ‘centroid’ method.

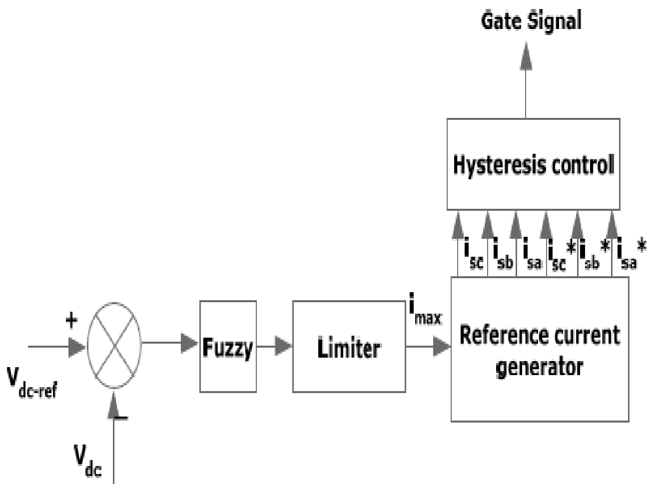


Fig.5.Conventional fuzzy controller.

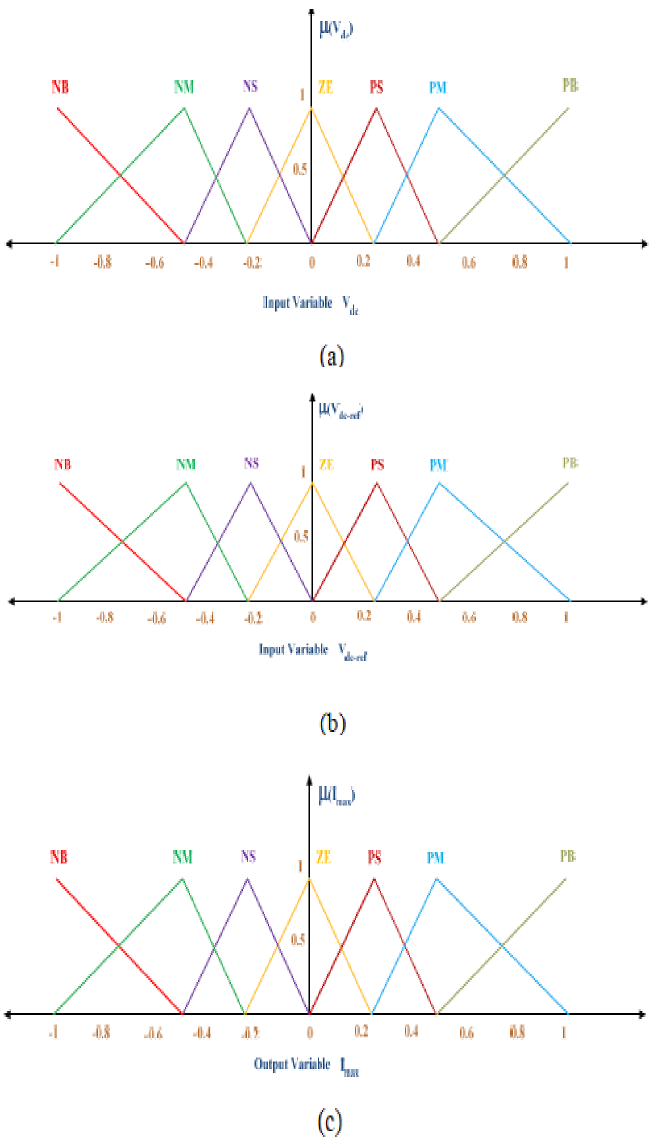


Fig.6. (a) Input V_{dc} normalized membership function; (b) Input $V_{dc\text{-}ref}$ Normalized Membership Function; (c) Output Imax Normalized Membership Function.

Fuzzification: the process of converting a numerical variable (real number) convert to a linguistic variable (fuzzy number) is called fuzzification.

De-fuzzification: the rules of FLC generate required output in a linguistic variable (Fuzzy Number), according to real world requirements, linguistic variables have to be transformed to crisp output (Real number).

Database: the Database stores the definition of the membership Function required by fuzzifier and defuzzifier.

Rule Base: the elements of this rule base table are determined based on the theory that in the transient state, large errors need coarse control, which requires coarse in-put/output variables; in the steady state, small errors need fine control, which requires fine input/output variables. Based on this the elements of the rule table are obtained as shown in Table 1, with'V_{dc}' and '$V_{dc\text{-}ref}$' as inputs.

TABLE II:

$V_{dc\text{-}ref}$ / V_{dc}	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	Z
NM	NB	NB	NB	NM	NS	Z	PS
NS	NB	NB	NM	NS	Z	PS	PM
Z	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PM	PB	PB
PM	NS	Z	PS	PM	PB	PB	PB
PB	Z	PS	PM	PB	PB	PB	PB

VI. SIMULATION RESULTS

Simulation results of this paper is shown in bellow Figs. 7 to 13.

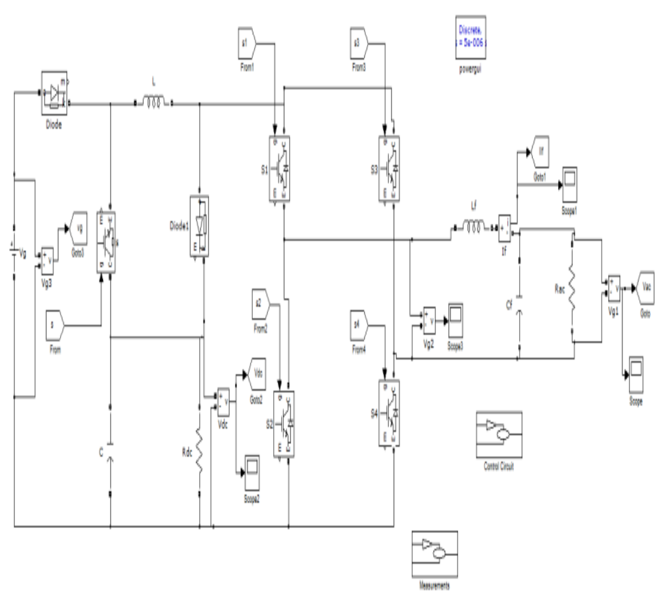


Fig.7. Matlab/simulink model of switched boost inverter with PI.

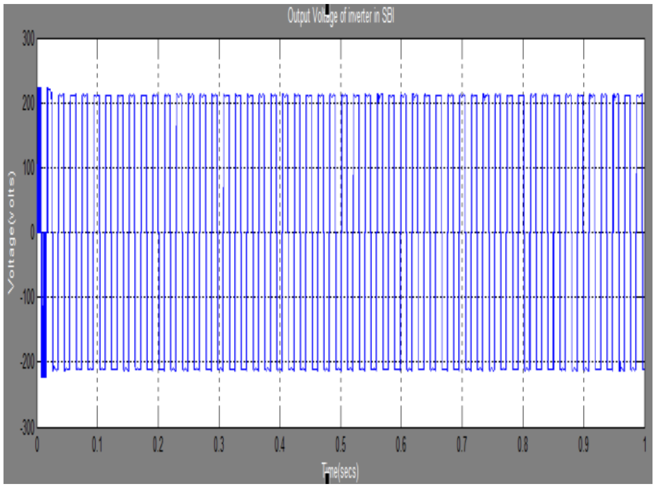


Fig.8. Shows the simulation of output voltage of SBI with PI.

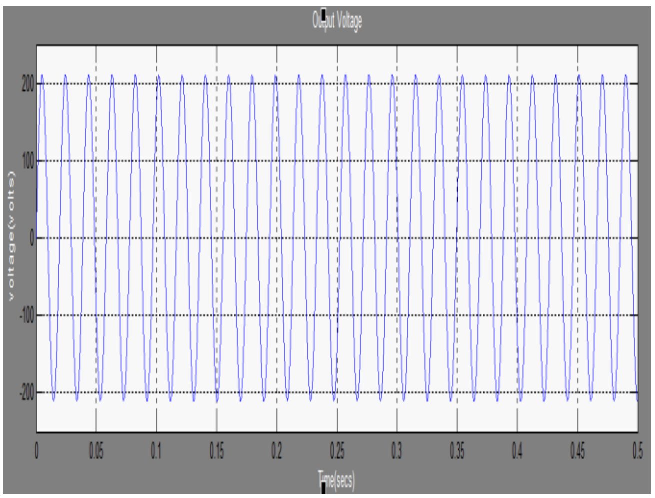


Fig.9. Shows the simulation of grid side voltage.

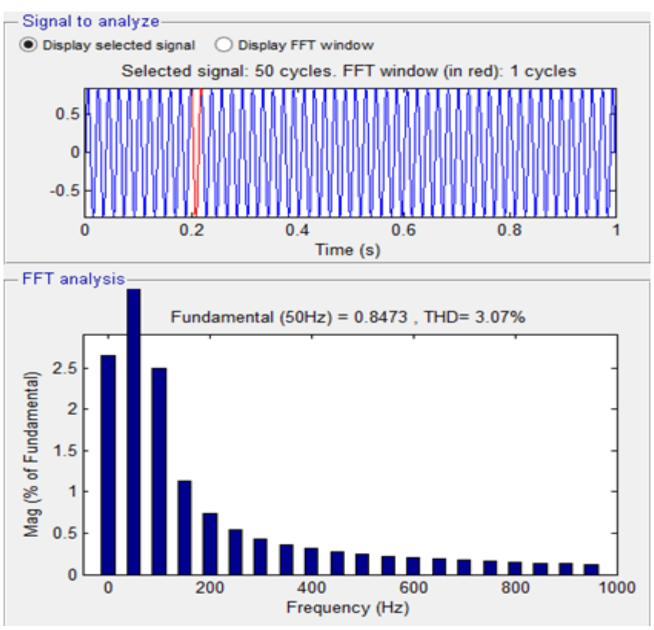


Fig.10. THD analysis of conventional converter using PI controller.

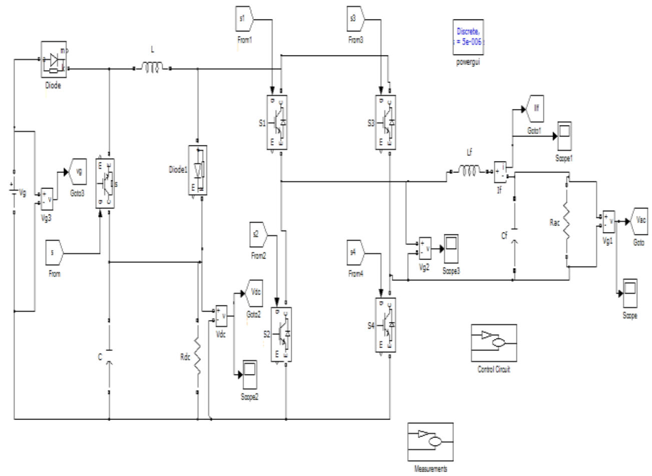


Fig.11.Matlab/simulink model of switched boost inverter with fuzzy controller.

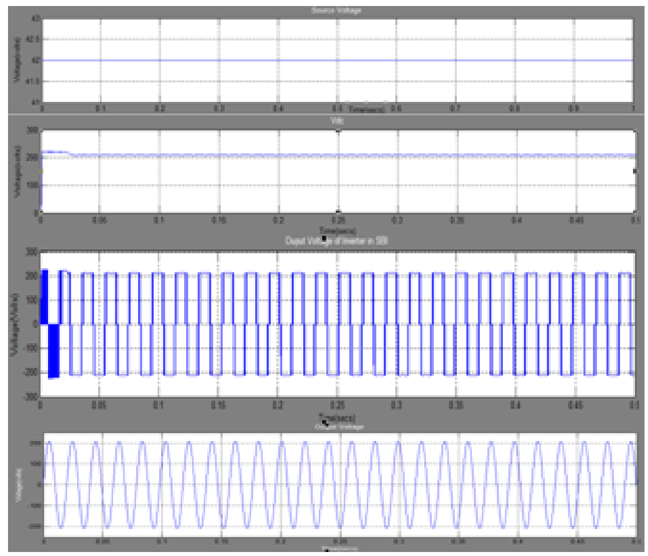


Fig.12. Shows the waveforms of source voltage, output voltage, grid voltage and grid current.

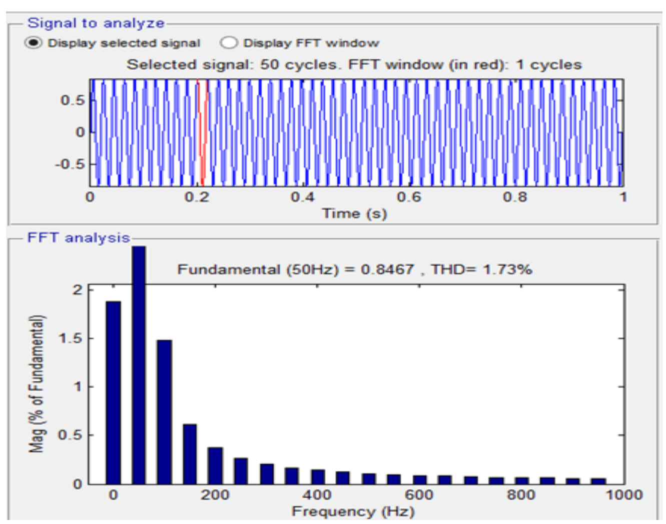


Fig.13.THD analysis of conventional converter using fuzzy controller.

VII. CONCLUSION

This project presents a novel power electronic interface called switched boost inverter (SBI) for dc nanogrid applications. It is presented with PI controller and fuzzy controller and results are discussed. The proposed work is simulated through MATLAB simulation.THD analysis is calculated for both PI and Fuzzy which is decreased for Fuzzy. Finally using Fuzzy logic controller grid side voltage is improved as in PI controller. These results confirm the suitability of SBI using Fuzzy for dc nanogrid applications.

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