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Fuzzy Controller Based Switched Boost Converter with Reduced Harmonics for Micro Grid Application

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Abstract: Z source converter is the improved version of Voltage Source Inverter (VSI) which utilizes shoot through state of the switches and can be operated in both buck and boost mode of operation. The major drawbacks of Z Source Converter (ZSC) is the high cost, more space and not suitable for lower power applications. In order to overcome these disadvantages, Switched Boost Converter (SBC) is proposed. The proposed converter overcomes the limitations of the conventional ZSC such as lower cost, compact space and less use of passive components. This feature of SBC makes it appropriate for micro grid applications. In this study, SBC is designed for micro grid applications with Proportional-integral controller as well as fuzzy logic controller and total harmonic distortions are compared.

Key words: Total harmonic distortion, switched boost converter, Z-source converter, fuzzy logic controller, distribution generation

INTRODUCTION

In conventional Distribution Generation (DG) grid which employs solar energy make use of inverter along with boost converter or buck converters for energy conversion.ZSC utilizes the advantages of shoot through states of the switches and is used for boost or buck the converted voltage (Ravindranath *et al*., 2013; Rabi, 2006; Farahani, 2008). Although, ZSC have several advantages, it suffers from drawbacks such as high cost, size and weight also less efficient in low power applications due to the use of 2 inductors and 2 capacitors. Therefore, the proposed new SBC topology overcomes the above said drawbacks with low THD. Switched boost converter are widely used in microgrid applications because it can be operated in both buck and boost mode with lower THD which satisfies the IEEE standards for micro-grid (Ramezani, 2010; Bashi *et al*., 2008; Haron *et al*., 2012).

Micro grids are modern, small-scale versions of the centralized electrical system (Khatib, 2010; Haron *et al*., 2012). Specific goals like reliability, reduced carbon emission and cost reduction are achieved by micro grid. Like the traditional power grid, micro grids can generate, distribute and regulate the power flow to the consumers in a particular locality or area.

The proposed Switched Boost Converter (SBC) works similar to ZSC and the input voltage is boosted by achieving the shoot-through state i.e., turning on the devices of the same leg, which may be suitable for various applications such as fuel cell, PV, distributed generation, adjustable speed drives, ups etc. This study organized as follows, the necessary technical details is explained in materials and methods. Followed by the result and discussion on the proposed SBC is designed in closed loop and the harmonic analysis of SBC with PI and fuzzy controller is compared. Final section details the conclusion of this study.

MATERIALS AND METHODS

SBC topology: SBC has the ability to produce the voltage lesser or greater than the input voltages by the proper utilization of shoot-through state of a converter bridge i.e., turning on the devices of same leg. The circuit diagram of SBC is shown in Fig. 1. The switched boost network in the converter circuit consists of a capacitor C, an inductor L, one active switch S_a and 2 diodes Da_1, D_{b1}. The SBC network is placed in between the dc source and an inverter bridge (Ravindranath *et al*., 2013). A LC filter is used to eliminate the harmonics present and is used to get desired output voltage.

Operation of SBC: The SBC is a combined buck and boost converter operated in 2 different modes i.e., shoot-through mode and non-shoot through mode.

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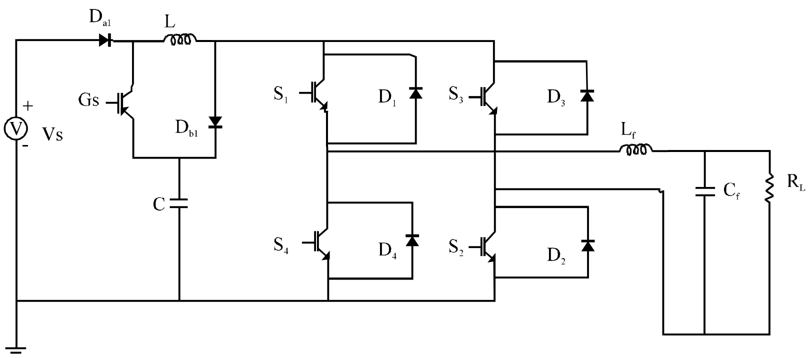

Fig. 1: Circuit diagram of SBC

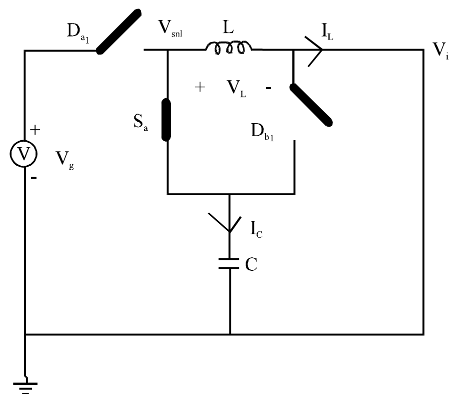

Fig. 2: SBC in shoot through state

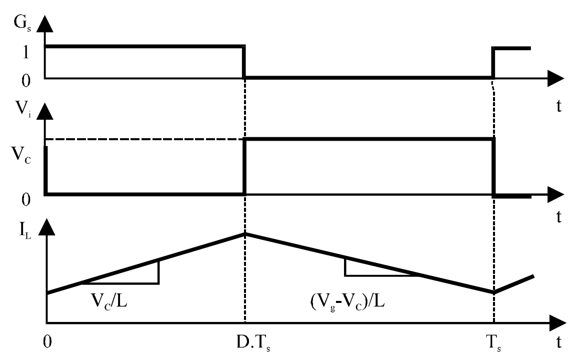

Fig. 3: Steady state waveforms of SBC

Mode 1: In this mode, switch S_a is turned on and diodes D_{a1} and D_{b1} are reverse biased since capacitor voltage is higher than the source voltage. In DTs interval, inductor current starts charging by discharging the capacitor voltage through the switch S_a and inverter bridge. The Fig. 2 shows the equivalent circuit of SBC in shoot-through mode for an interval DTs for a switching cycle Ts. The steady state waveforms of SBC are shown in Fig. 3. From the waveforms, the voltage and current values of inductor and capacitor connected to switch S and the inverter voltage are given as:

$$V_L(t) = V_c(t)$$

$$I_C(t) = -I_L(t)$$

$$V_I(t) = 0$$

Mode 2: In the remaining duration of interval (1-D) Ts. i.e., non shoot-through mode, switch S_a is turned off and the diodes are turned on. In this interval, capacitor is charged through the diodes and inductor L. The inverter gets the boosted input voltage from the inductor and source. The equivalent circuit of SBC in non shoot-through mode for an interval (1-D) Ts for a switching cycle Ts is shown in Fig. 4. In this interval, the voltage and current values are given as:

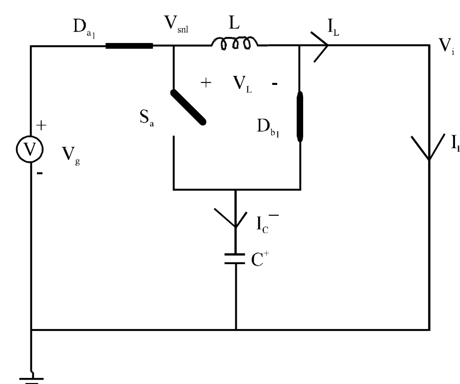

Fig. 4: SBC in non shoot-through state

$$V_g - V_C = V_L$$

$$I_L = I_I + I_C$$

$$V_I = V_C$$

PWM technique: In this proposed SBC, a special type of PWM technique i.e., using the logic gate operation which produces the control signals for gate which reduces the switching losses and maintains the constant switching frequency when compared to the traditional PWM control techniques. In this study, control signals are generated by comparing the high frequency triangular carrier signal to the sinusoidal modulation signal $V_m(t)$ and $-V_m(t)$. The carrier signal frequency is chosen such that $f_s >> f_0$. Switches S1 and S2 obtain their gate control signals by comparing $V_{tri}(t)$ and $V_m(t)$, respectively and the shoot-through periods ST1 and ST2 are obtained from the comparison of $V_{tri}(t)$ with constant voltage V_1 and V_2 is shown in Fig. 5. Remaining switches obtain their gate signals by using the logical expression is given below and the obtained waveforms of PWM control signals in MATLAB simulation is shown in Fig. 6:

$$G_{S3} = \overline{G_{S2}} + ST_1; G_{S4} = \overline{G_{S1}} + ST_2; G_{Sa} = ST_1 + ST_2$$

Controller design: The main goal of the controller is to control the system output to a desired reference value by

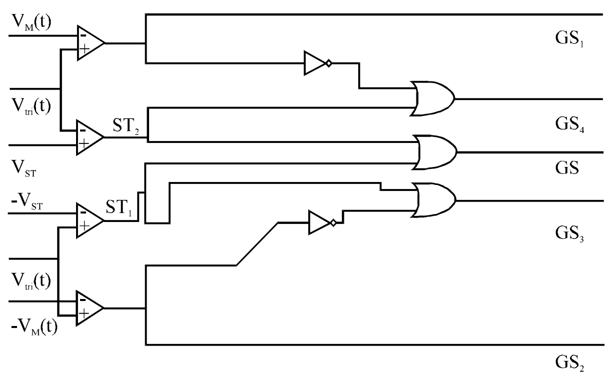

Fig. 5: Gate control signals for SBC

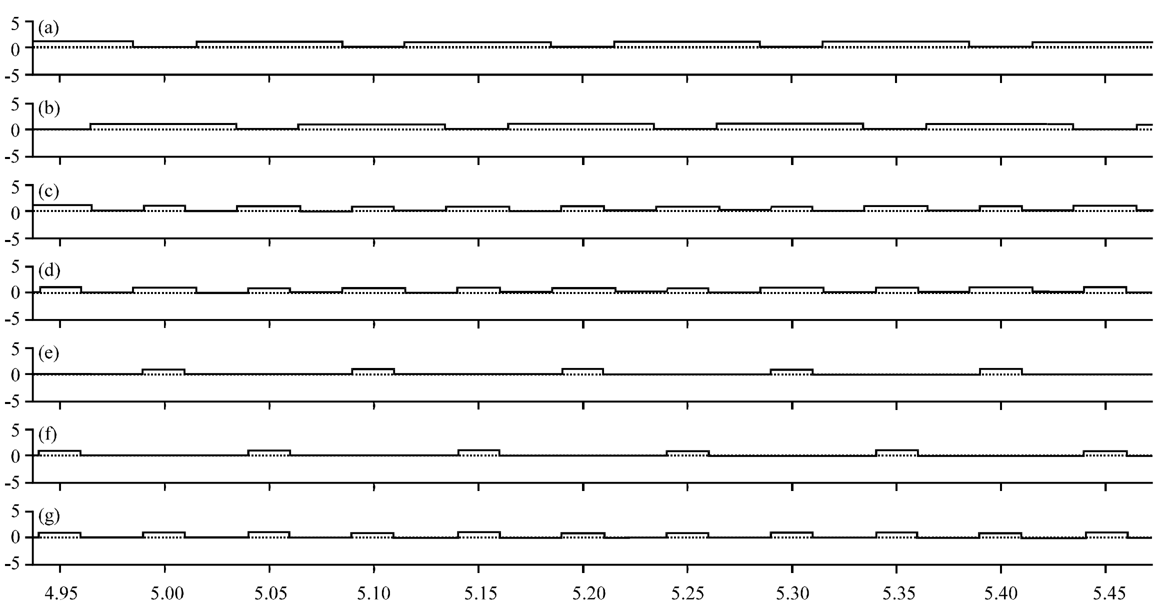

Fig. 6(a-g): Obtained PWM control signals in MATLAB (a) Switch 1, (b) Switch 2, (c) Switch 3, (d) Switch 4, (e) ST1, (f) ST2 and (g) Switch 5 using the feedback action. For this converter, both PI as well as FLC is implemented. The Fig. 7 shows overall design of the converter using a controller.

PI controller: PI controller is often widely used in many applications since it eliminates the steady state error and does not require immediate response of the system. The error value between the actual output of the system and desired reference value is given as the input to the controller. After doing appropriate controlling action, it provides an input to the converter to get the desired reference value and the system become stable even if any disturbance occurs (Ma and Huang, 2011; Porasad and Hossein, 2008).

The Fig. 8 shows the schematic diagram of PI controller consists of K_P and K_I. K_P term proportional to the magnitude of the error used to eradicate the steady state error and K_I term proportional to the integral of the error used to takes away the offset between system output and desired set value. The signal which is sent to the controller is the addition of K_P and K_I term. The value of K_P and K_I can be found by starting the tuning process with the large value of $K_I$and smaller value of K_P. Increase the K_P value until the response is acceptable and decrease the K_I value until the steady state error is vanished in acceptable time. The transfer function of PI controller and the values used in the simulation is as follows:

$$PI(s) = k_p.s+(k_i/s)$$

$$K_p = 10 \text{ and } K_i = 1$$

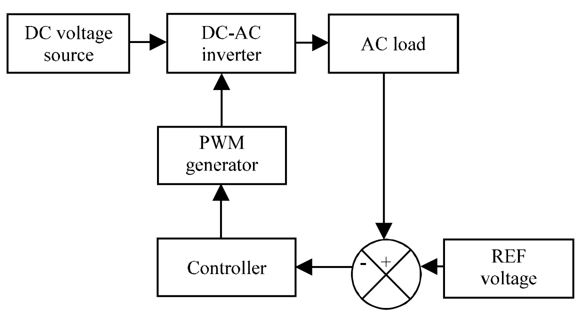

Fig. 7: Block diagram of SBC with controller

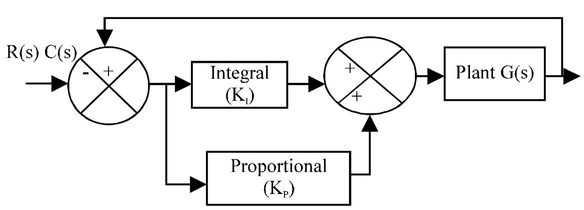

Fig. 8: Schematic diagram of PI controller

Fuzzy Logic Controller (FLC): FLC has a dramatic usage in many applications since it is a rule based approach and does not require any numerical value of the system. The fuzzy logic controller is a user-defined, simple, robust and easily changeable and can accept multiple inputs and outputs (Yu *et al*., 2013; Dursun, 2008; Ghasemi *et al*., 2009). Even if the inputs are noisy, it will provide précised output. The Fig. 9 shows the block diagram of FLC which involves three stages.

Fuzzy controller for the proposed inverter is established by creating input membership function for the error and change in error and output membership function for duty ratio D. Membership functions are the graphical representation of the data which are denoted by linguistic variable. There are several membership functions such as triangular, trapezoidal and Gaussian etc. Here, triangular membership function is used (Ma and Huang, 2011).

Fuzzification is the conversion of numerical input data to fuzzy value. This process is done by creating membership function for the input and output data. Rule evaluation is the formulation of certain rules for controlling the output variable within the given range and the rules are simply defined in IF-THEN rule with

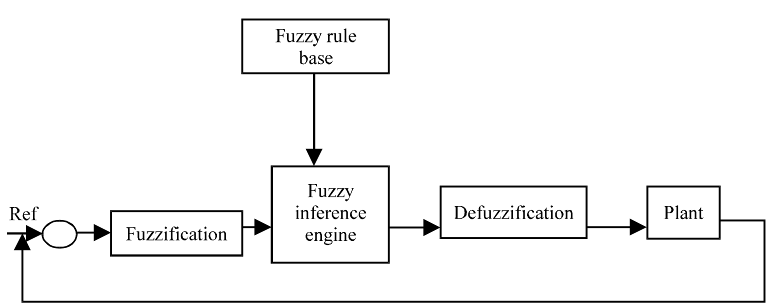

Fig. 9: Schematic diagram of fuzzy controller

condition and conclusion. The Table 1 shows the rules for this proposed converter (Thiagarajan *et al*., 2008). Defuzzification is the conversion of the fuzzy value into the crisp data as an input to the system. According to the membership functions of output variable, defuzzification is executed to find the crisp values using the Centre Of Mean (COM).

RESULTS AND DISCUSSION

Simulation and results of SBC: Figure 10 shows the closed loop simulation of the SBC. The converter switches are controlled by the PI controller/FLC at a carrier frequency of 10 kHz and the parameters used for simulation is given in Table 2. The output voltage and THD of the converter using 2 controllers are observed and compared.

Figure 11 and 12 shows the closed loop simulation output of SBC with PI controller and fuzzy logic controller in which output voltage remains constant for dynamic load conditions. The Table 3 shows that both ZSI and SBI are operated with same voltage and constant boosted output voltage is obtained even if any changes in input voltage using two controllers. The THD obtained with fuzzy controlled SBC is lower as compared with conventional ZSI and the requirements of components is also less for SBC than ZSI. The failure of any of the components in SBC will not affect the left over elements in the converter.

Z-source inverter: From the obtained waveforms of PI-SBC, FLC-SBC and PI-ZSI, the DC input voltage of 150 V is boosted to the output voltage of 230 V with modulation index of 0.5 (Fig. 13). The Fig. 11b and 12b shows the inductor current waveform. From the figure, it is clear that the inrush current is decreased by using the fuzzy controlled switched boost converter by selecting accurate values. It is also noted that the inductor current

Table 1: Fuzzy rule table

cee	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	PS	NS	ZE	PS	PM
PS	NM	NS	PM	ZE	PS	PB	PB
PM	NS	ZE	PB	PB	PM	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

Table 2: Simulation parameters

Parameters	Values
Input voltage (V)	150
Output voltage (V)	230
Inductor (L) (mH)	5
Capacitor (c) (μF)	100
Filter inductor (L_f) (mH)	350
Filter capacitor (C_f) (μF)	10
Load resistance (Ω)	100

Table 3: THD comparison

Parameters	ZSI with PI controller	SBC with PI controller	SBC with fuzzy controller
Input voltage	150.00	150.00	150.00
Output voltage	230.00	230.00	230.00
THD (%)	3.53	1.33	1.02

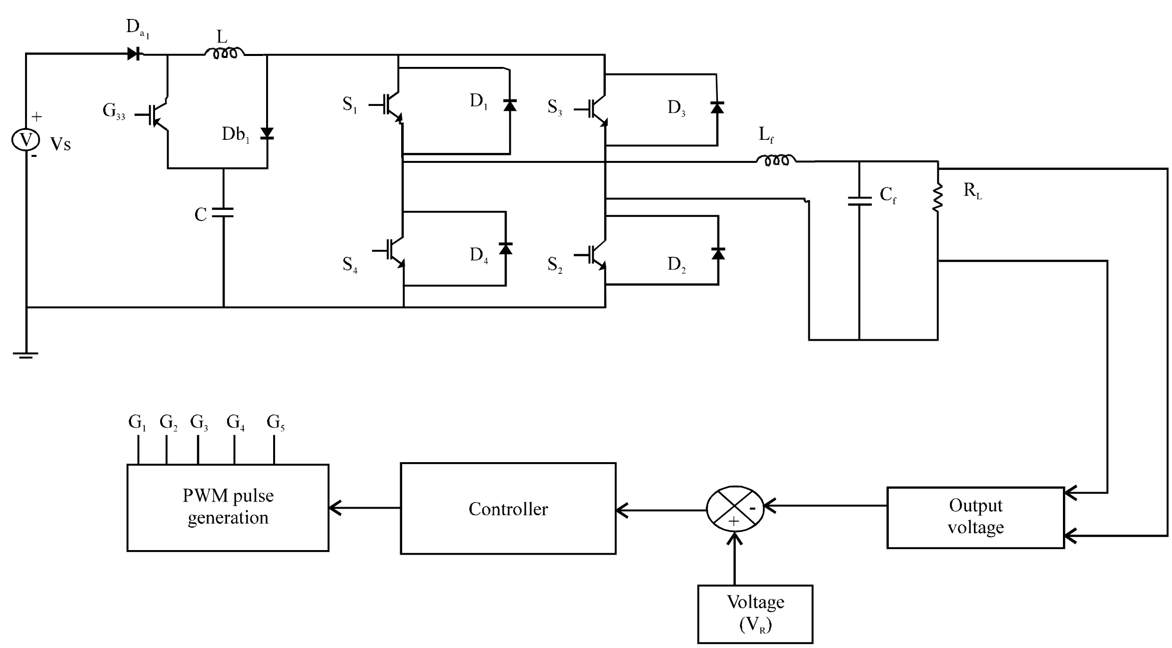

Fig. 10: Simulation model of SBC

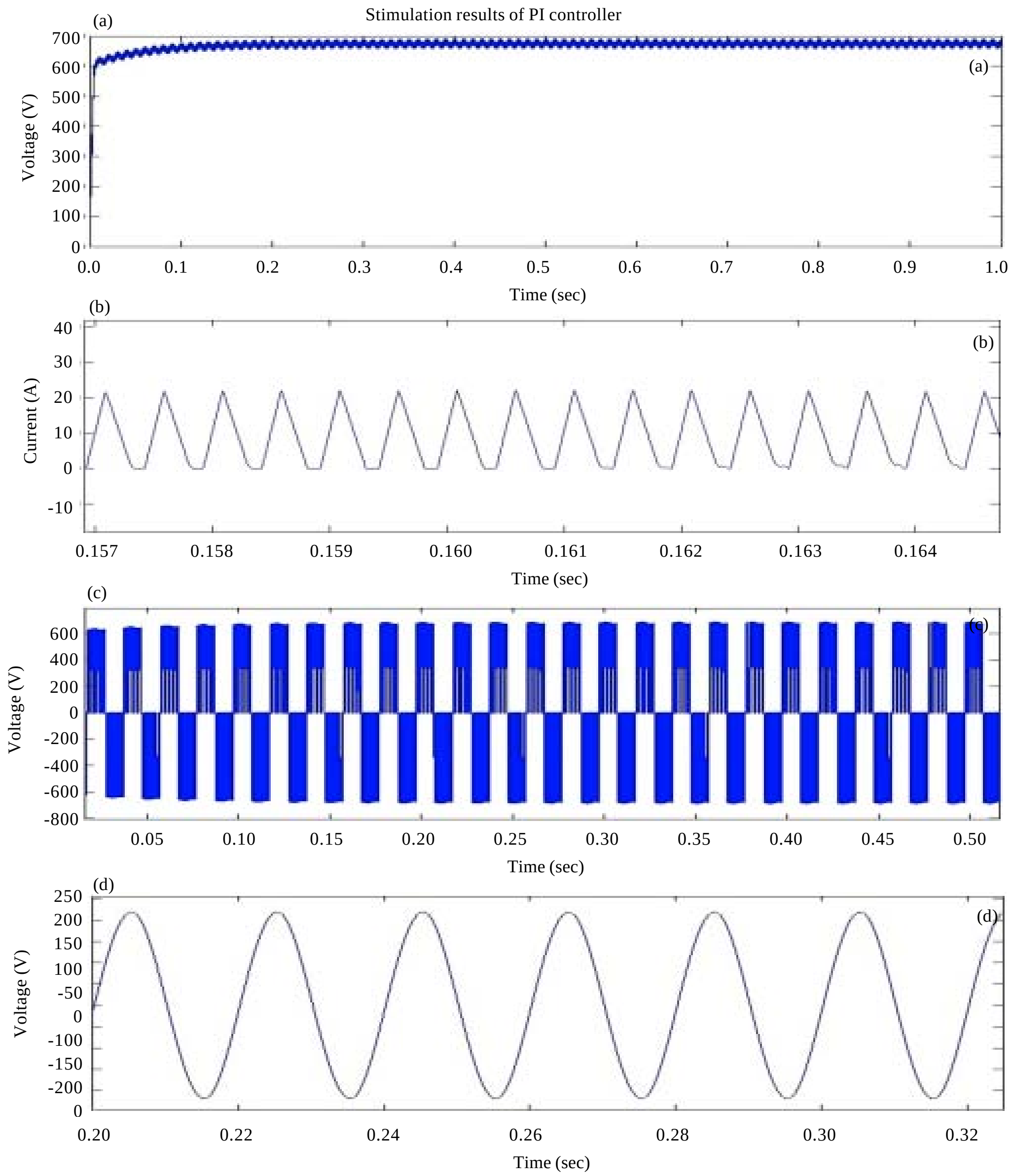

Fig. 11(a-d): Output waveform of (a) Voltage across source side capacitor, (b) Current through inductor, (c) Unfiltered output voltage of an inverter and (d) Filtered inverter output voltage of SBC with PI controller

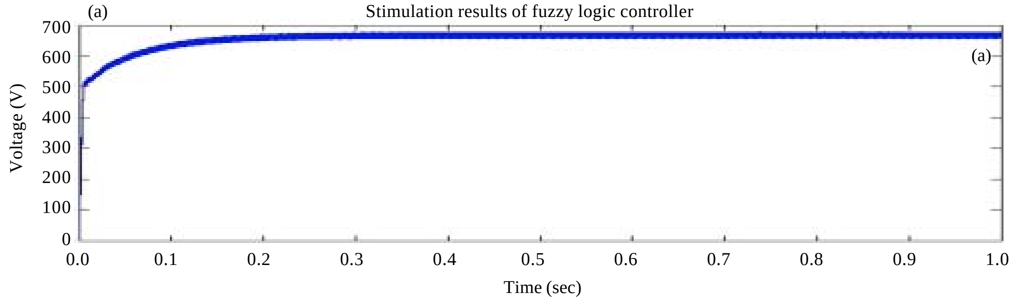

Fig. 12(a-d): Continue

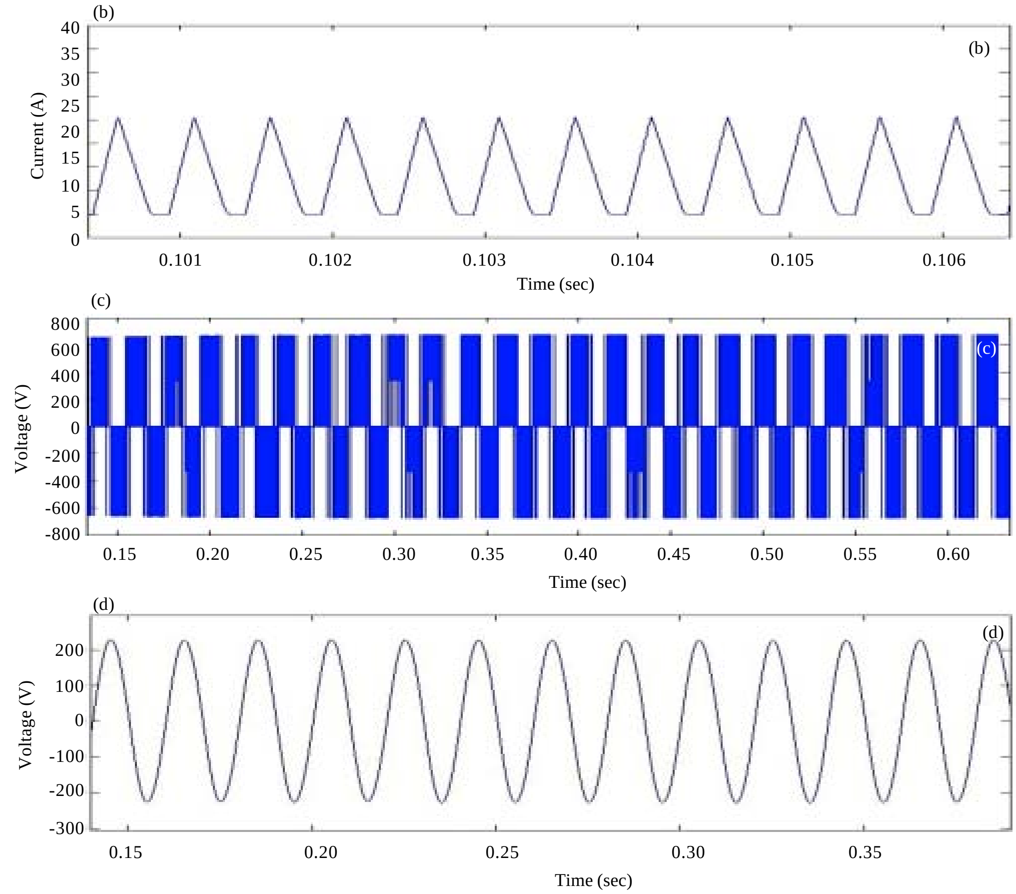

Fig 12(a-d): Output waveform of (a) Voltage across source side capacitor, (b) Current through inductor, (c) Unfiltered output voltage of an inverter and (d) Filtered inverter output voltage of SBC with fuzzy logic controller

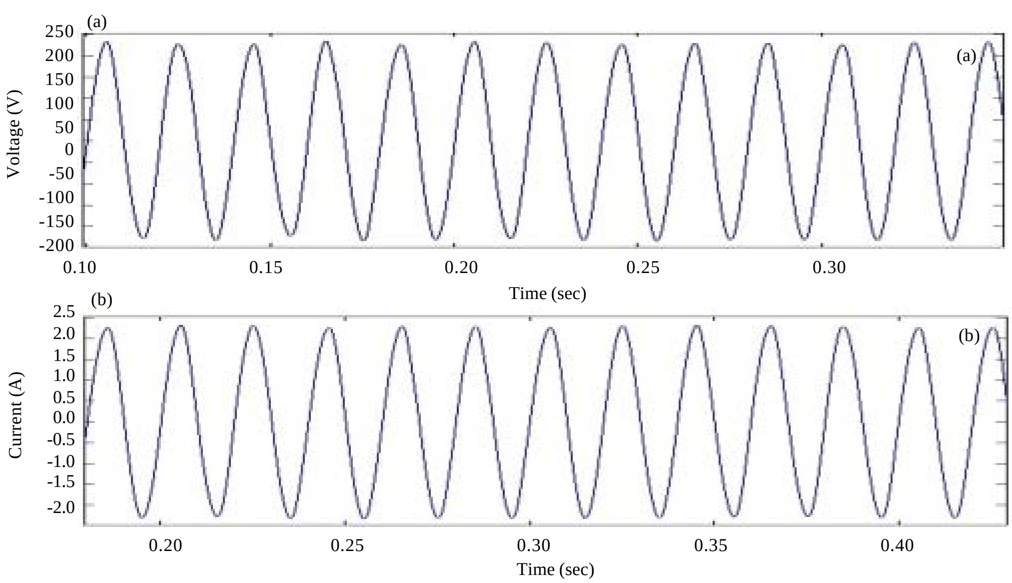

Fig. 13(a-b): Output waveform of (a) load voltage and (b) load current of ZSI with PI controller of SBC with FLC exhibits lesser harmonics than the SBC with PI controller. The Fig. 11a and 12a shows the capacitor voltages. From the Fig. 11a and 12a, it is noted that SBC with PI controller exhibits lesser steady state error and lesser rise time than the SBC with FLC.

CONCLUSION

This study presents the design and implementation of SBC using MATLAB/Simulink. This proposed closed loop structure of the SBC with PI controller and the fuzzy logic controller are simulated using MATLAB/Simulink. The closed loop simulation results of SBC with PI and FLC controller shows that the SBC with fuzzy logic controller exhibits low total harmonic distortion than the PI controller. This result implies that that the closed loop fuzzy controlled SBC exhibits the THD of 1.02% which is well within IEEE standard and makes it best opted for micro grid applications.

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