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Fuzzy Based Single Phase Double-tuned Current Source Inverter with Reduced Harmonics for Microgrid

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Abstract: This study proposes a Current Source Inverter (CSI) consists of double-tuned resonant circuit at the source side for boosting the input voltage with low Total Harmonic Distortion (THD) which may suitable for microgrid applications. This proposed current source double-tuned inverter overcomes the drawbacks of conventional CSI by reducing the losses and space. Harmonics at the DC side input voltage is attenuated by the construction of double tuned circuit. The double tuned CSI with different control topologies are designed and simulated using MATLAB/Simulink.

Key words: Pulse width modulation, proportional-integral controller, fuzzy logic controller, microgrid, current source inverter, total harmonic distortion

INTRODUCTION

Energy crisis and environmental impacts in the world may increase the suitability of renewable energy source such as photovoltaic (PV), wind, hydro, nuclear, etc. Among these different renewable energy resources, PV is top priority in micro grid applications due to its easy access (Yang *et al*., 2010). Microgrid is the smallest electricity generation, energy storage, distribution of energy to many consumers and all the grids are connected to the main power grid. Microgrid would achieve specific goals such as reliability, efficiency, cost reduction and reduced carbon emission (Dasgupta *et al*., 2011; Mehrizi-Sani and Iravani, 2010).

The CSI may suitable for microgrid applications since the DC link in CSI use inductors to regulate the current ripple effectively (Porasad and Hossein, 2008; Wang *et al*., 2011). Several types of converters with various control schemes proposed in the literature for micro grid applications (Porasad and Hossein, 2008; Farahani, 2008; Ramezani, 2010; Haron *et al*., 2012; Bashi *et al*., 2008).

This study proposed CSI consists of double tuned resonant circuit connected between the source and main inverter bridge to regulate the current ripple at the DC side and the main inverter bridge is to produce an AC output. CSI can be operated in boost mode with the help of double tuned circuit by shorting the devices of same leg. Proposed CSI overcomes the drawbacks of conventional CSI as it requires additional circuit for boosting the input voltage and it can also reduce the harmonics existed in the system. The proposed inverter eliminates the necessity of bulky transformer to boost the voltage and also increase the efficiency, stability, simplicity of the system (Alajmi *et al*., 2013; Kim *et al*., 2010).

MATERIALS AND METHODS

Current source inverter topology: A conventional current source inverter needs step-up transformer for boosting the voltage and MPPT to track the maximum power for certain microgrid PV applications and hence it decreases the efficiency and increases cost of the overall system (Kjaer *et al*., 2005; Petrone *et al*., 2011; Wu *et al*., 2011). In order to mitigate the above drawbacks of conventional inverter, the proposed inverter utilizes the double-tuned filter circuit at the DC-side to boost the voltage (Fig. 1).

The double-tuned resonant filter consists of equal values of inductance and capacitance which has the ability to smoothen the DC-line current where C1, C2 are the resonant filter capacitances and L_1, L_2 are resonant filter inductances is shown in Fig. 2. In a single phase current source inverter, even order harmonic are generated in the DC-link current. Large DC-link inductor (L_s) is required in the DC side for mitigating these harmonics in the DC side and its effect on AC side. Large inductance in conventional current source inverter increases weight, cost and size also decreases the efficiency. This circuit connected series with the inductor to reduce the lower order harmonics.

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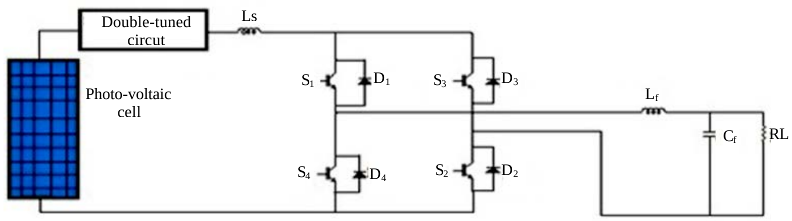

Fig. 1: Circuit diagram of CSI with double tuned resonant circuit

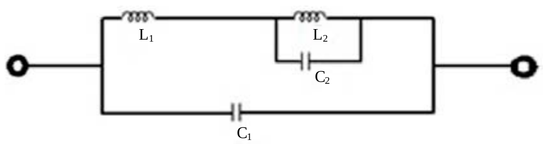

Fig. 2: Double-tuned resonant filter

Double-tuned resonant filter: The design of double-tuned filter consists of two equal values of inductors and two equal values of capacitors as shown in Fig. 2 are mainly employed for harmonic suppression and it also have the capability to smooth the DC line current where C1, C2 are the resonant filter capacitances and L1, L2 are resonant filter inductances. The parameters used in the filter are given in Eq. 1-3 (Alajmi *et al*., 2013). In order to suppress the harmonics generated in the DC side and its impact on the AC side, filters are used. Here it needs a large inductance on the dc side since it increases the size, cost of the system and decreases the efficiency, so a tuned circuit is proposed. The double-tuned filter is connected in series with inductor L_s to reduce the lower order harmonics and also 2nd and 4th order harmonics generated in the line current of DC. Therefore, the proposed filter reduces the overall weight and cost of the system and increases the efficiency. A double-tuned filter is connected in series with inductor L_s to reduce the lower order harmonics. After filter design installations, the harmonics are greatly reduced to low values that are shown in the results.

$$C_1 = \left[\frac{L_2C_2 - \frac{1}{\omega^2}}{\omega^2 L_1 L_2 C_2 - L_1 - L_2}\right] \tag{1}$$

$$C_2 = \left[\frac{-L_2}{\left[\frac{L_2}{C_1} - \omega^2 L_1 L_2\right]} + \frac{1}{\omega^2 L_2}\right] \tag{2}$$

$$L_2 \leq 1.778\, L_1 \tag{3}$$

Control techniques: A PWM control technique proposed in the study is used to generate the switching control pattern in a single phase CSI as shown in Fig. 3. The gate control signals are generated by comparing the carrier signal with higher frequency to a reference signal of lower frequency. Here, two high frequency carrier signals are compared with a single reference signal to supply adequate short circuit current after every switching cycle in order to boost-up the voltage (Alajmi *et al*., 2013). Two carrier signals are shifted by 180° where one signal is used for switching the lower switches and another for upper switches. During every switching period, at least one of the lower and upper switches in either arm is turned on in order to obtain a continuous DC current.

Controller design: In this study, in order to maintain a constant inverter output voltage various controllers such as PI controller as well as Fuzzy Logic Controller (FLC) are used (Ghasemi *et al*., 2009; Dursun, 2008). The performance of the designed controllers are analysed for various loading conditions (Fig. 4).

PI controller is widely used in many applications since it is easy to implement and quite robust. It is needed to minimize the steady-state error to acquire a good response. The controller k_p and k_i values are tuned to get the desired output. The PI controller transfer function is given as:

$$PI(s) = K_P + \frac{K_I}{S}$$

where K_p and K_i represents proportional constant and integral constant.

The error value obtained while comparing the measured value and desired value is given as input to the controller and the output received from this controller is further given to the system to obtain the desired value. PI controller starts the controlling process by tuning the values of k_p and k_i. In this study, the PI controller is tuned for K_p and K_i values of 10 and 0.2 respectively (Fig. 5).

Fuzzy logic controller system consists of membership functions for input and output, rule-based controller,

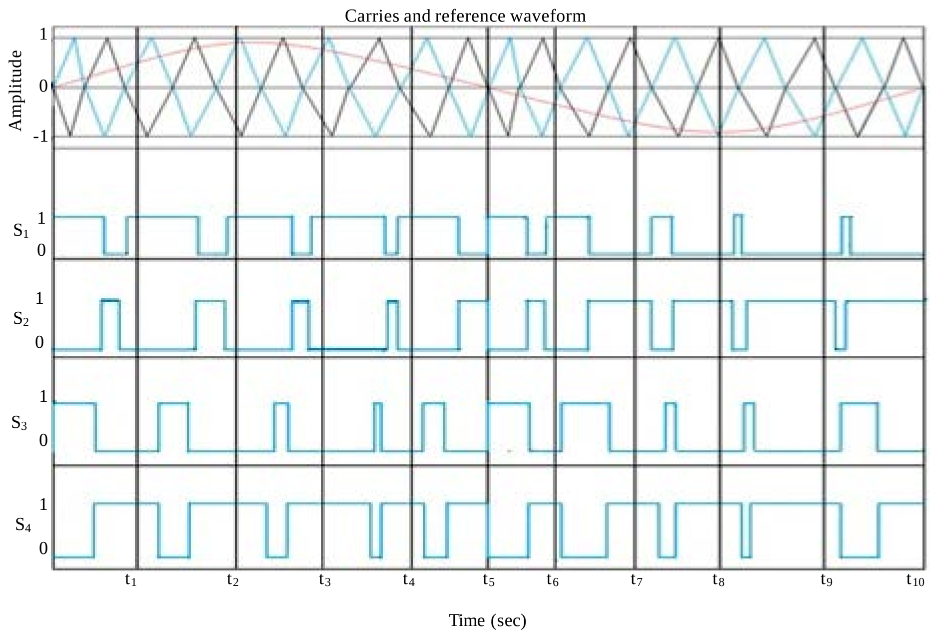

Fig. 3: Gate control signals for switches in CSI

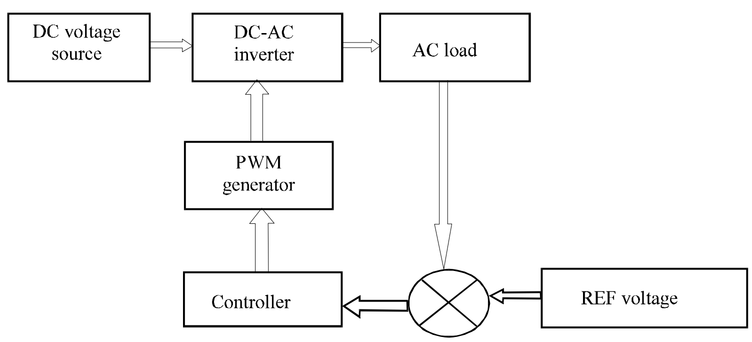

Fig. 4: Block diagram of CSI with controller

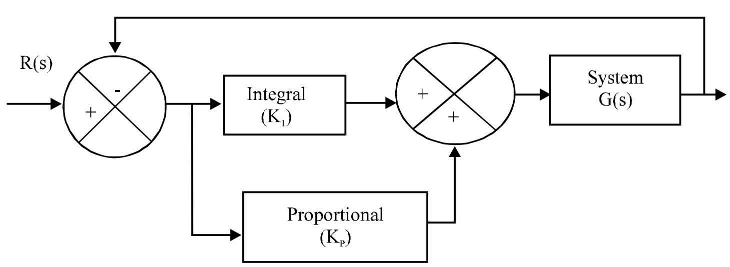

Fig. 5: Schematic diagram of PI controller

linguistic variable. By implementing the FLC the output voltage can be controlled and the inputs to the fuzzy logic are error in voltage and change in voltage error and controller output is given to the system as the gate control signals to get the desired value (Alajmi *et al*., 2011). In MATLAB/Fuzzy toolbar, the FLC is simulated with two inputs and one outputs.

The fuzzy logic needs three consecutive steps which are:

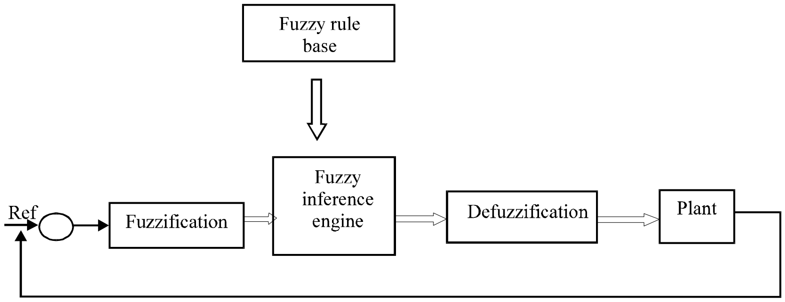

Fig. 6: Schematic diagram of fuzzy controller

Table 1: Rule table

	Ce						
e	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	PM	PB
PS	NM	NS	PM	ZE	PS	PB	PB
PM	NS	ZE	PB	PB	PM	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

- Fuzzification
- Inference
- Defuzzification

Fuzzification is the first step involved in fuzzy logic to convert the crisp variables into fuzzy variable using the membership functions (Fig. 6). Membership functions are graphical representation of input and output data that are named by linguistic variable. In this study, seven-triangular membership functions are used namely negative small-NS, Negative Medium, NM, Negative Big-NB, Positive Small-PS, Positive Medium-PM Positive Big-PB, Zero Error-ZE. The second step involved in the fuzzy logic controller is the Inference in which rules are designed to interact with input and output values. It uses IF-THEN rule with a condition or conclusion to determine the system output response (Table 1). Last step of the controller is defuzzification. Since the controller output is a fuzzy value, this last stage of controller changes the fuzzy data into crisp data by using the output membership functions. Bisector method is carried out in the defuzzification process.

RESULTS AND DISCUSSION

The current source inverter design is simulated using the MATLAB/Simulink tool. The Fig. 7 shows simulation of the CSI with PI controller and FLC to control the output voltage. At a carrier frequency of 10 KHZ, the output voltage and the THD are observed and compared.

Table 2: Simulation parameters

Parameters	Values
Input voltage (V)	50
Output voltage (V)	230
Inductor (L_1,L_2 andL_s) (mH)	5
Capacitor (C_1 and C_2) (μF)	10
Filter inductor (L_f) (mH)	100
Filter capacitor (C_f) (μF)	100
Load resistance (Ω)	100

The Fig. 7 shows the overall diagram of the CSI using the two controllers and the THD for outputs obtained are compared for the controllers used. The simulation parameter for the above figure has been mentioned in Table 2.

The Fig. 8 and 9 shows the simulation schematic of both PI controller and FLC, respectively. The variation of THD in different method has been tabulated in Table 3. It is observed that the THD has been reduced to much satisfactory value in FLC than compared to PI controller. Also, the output voltage remains constant even if there is any change in the source voltage and load.

The simulation results are obtained circuit using FLC and proportional integral controller is listed in Table 3. For a given DC voltage of 50 V a boosted output AC voltage of 230 V is obtained by mitigating the harmonics in both DC and AC side with Proportional integral controller and FLC and it reduces the size, cost of the system. It is observed that a lower THD is obtained by grid connected CSI with fuzzy logic controller when compared to PI controller.

The PV array output voltage is shown in Fig 8. From the figure it is clear that the voltage remains same for conventional and proposed CSI with PI controller and FLC (Fig. 10).

Figure 11(a-c) represents the output voltage obtained across the R-load without grid connected by using conventional PI controller, proposed PI controller and fuzzy controller, respectively.

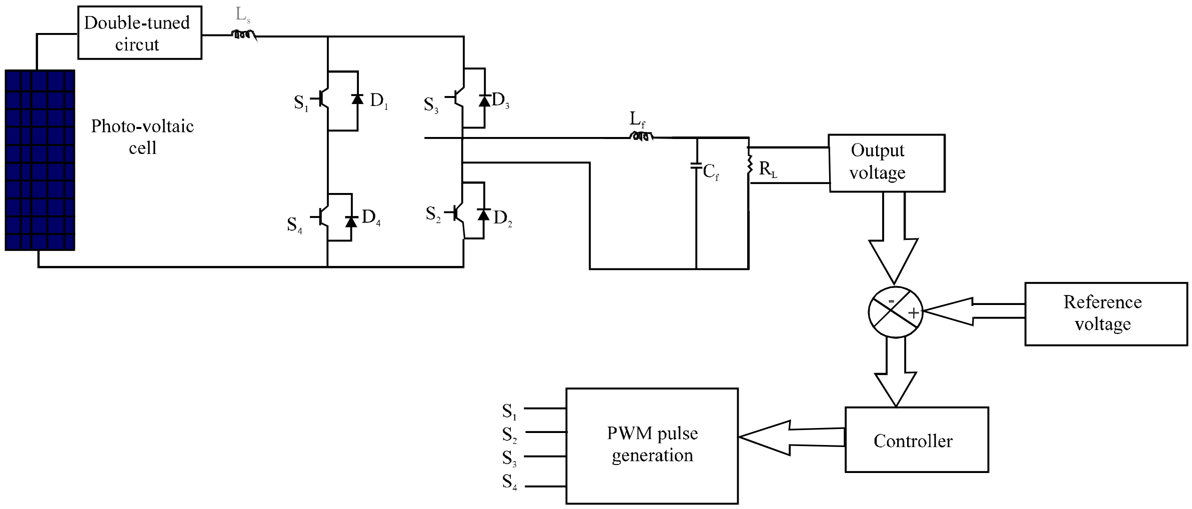

Fig. 7: Overall model of CSI

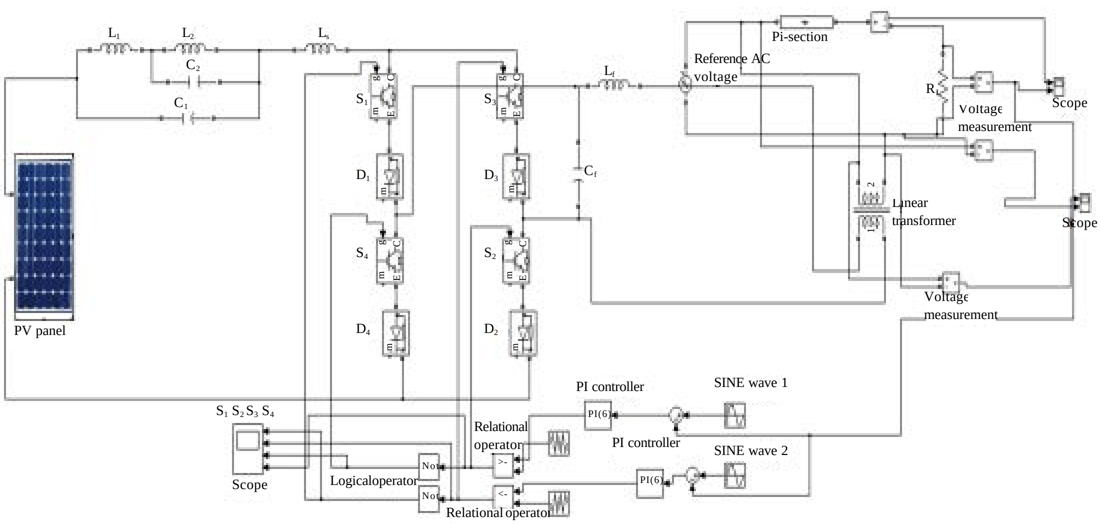

Fig. 8: Grid connected Simulink model of CSI proportional integral controller

Table 3: Analysis of THD with fuzzy logic controller and PI controller

Parameters	Proposed CSI with PI controller	Conventional CSI with PI controller	Fuzzy controller
Input voltage (V)	50	50	50
Output voltage (V)	230	230	230
THD for grid connected load (%)	2.45	4.87	0.02

Figure 12(a-c) represents the waveform of load current obtained without grid connected by using conventional PI controller proposed PI controller and FLC, respectively.

Figure 13(a-b) represents the waveform of output voltage obtained across the R-load for the proposed PI controller and the FLC, respectively when the grid is connected.

Figure 14(a-b) represents waveforms of the load current for the proposed PI controller and the FLC, respectively when the grid is connected.

Figure 15(a-c) represents FFT analysis of the output voltage for the proposed PI controller and the FLC, respectively when the grid is connected. In the FFT analysis shown above it is clear that the THD of double

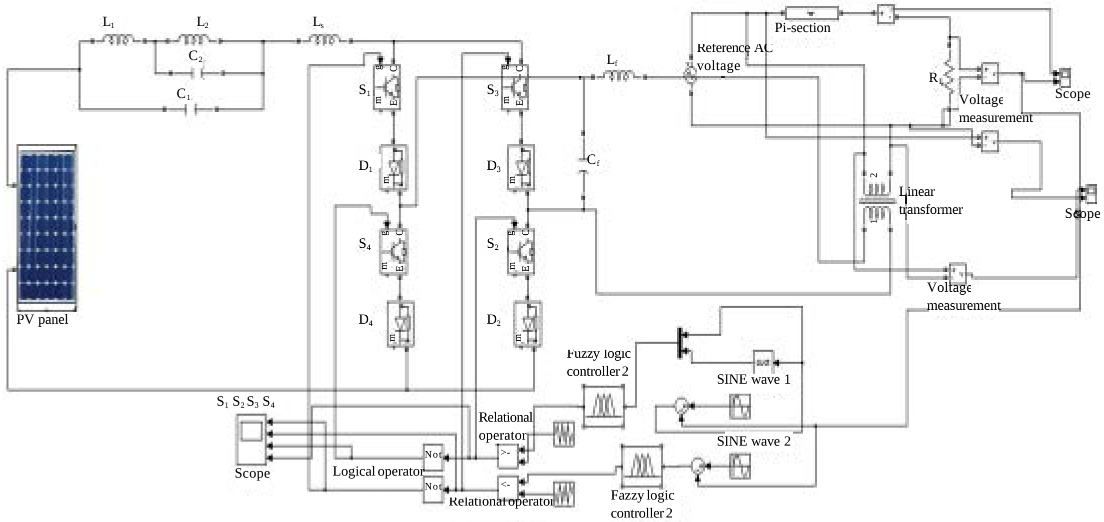

Fig. 9: Grid connected simulink model of CSI fuzzy logic controller

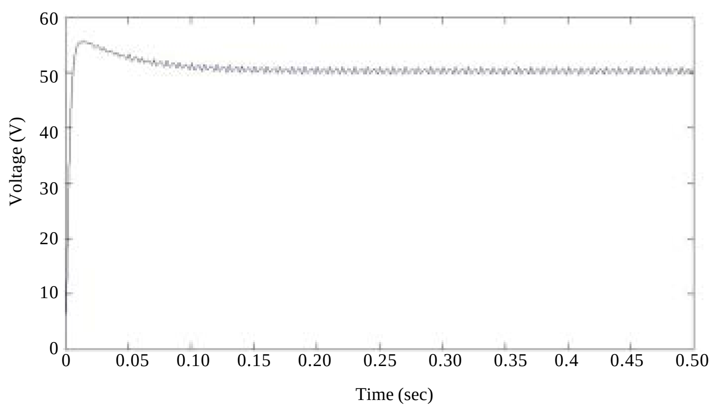

Fig. 10: PV output voltage

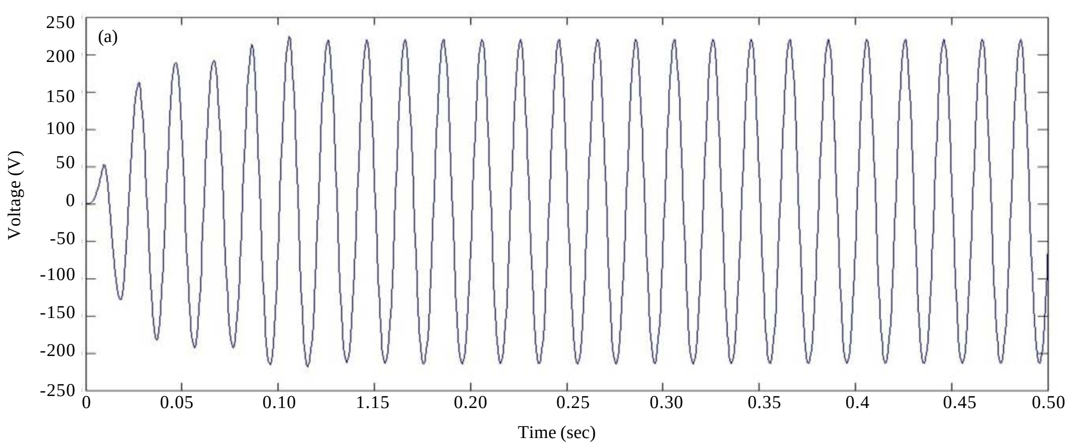

Fig. 11(a-c): Continue

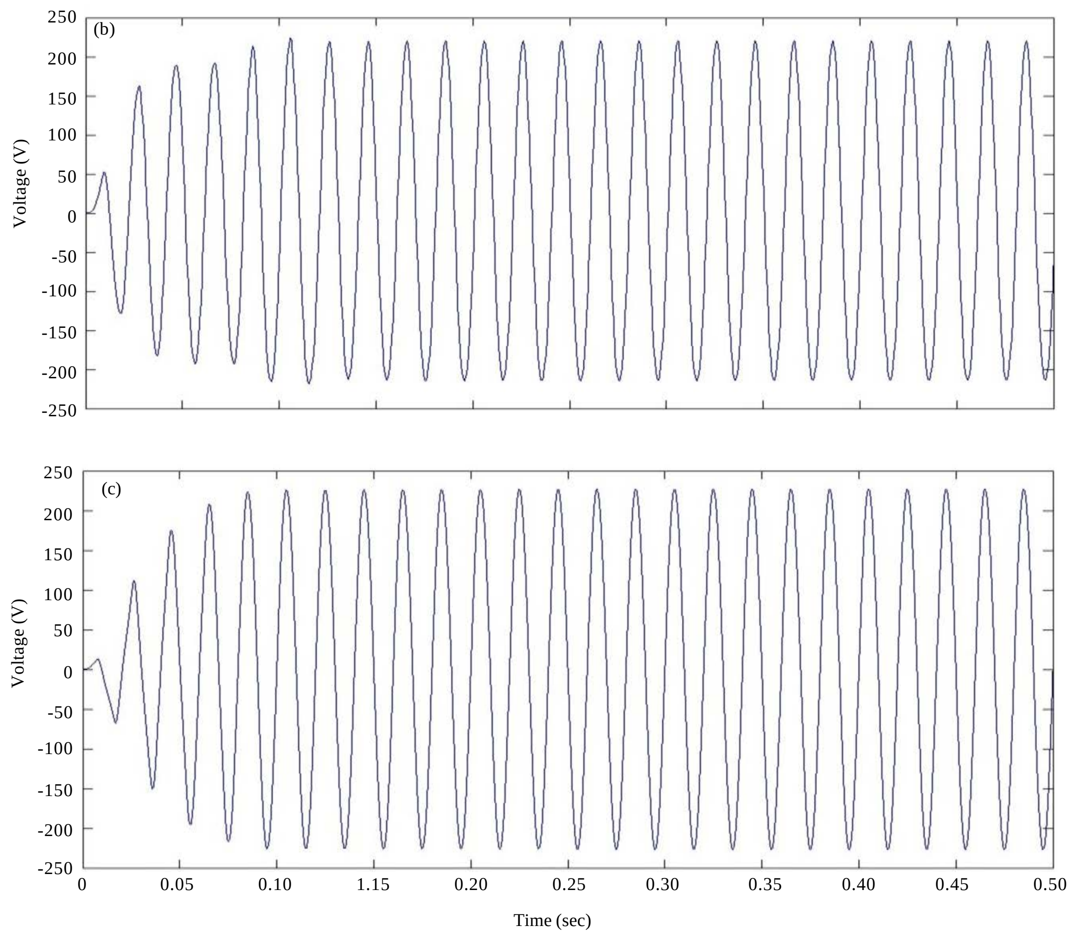

Fig. 11(a-c): Output voltage of proposed integral controller (a) Conventional (b) Proposed and (c) FLC

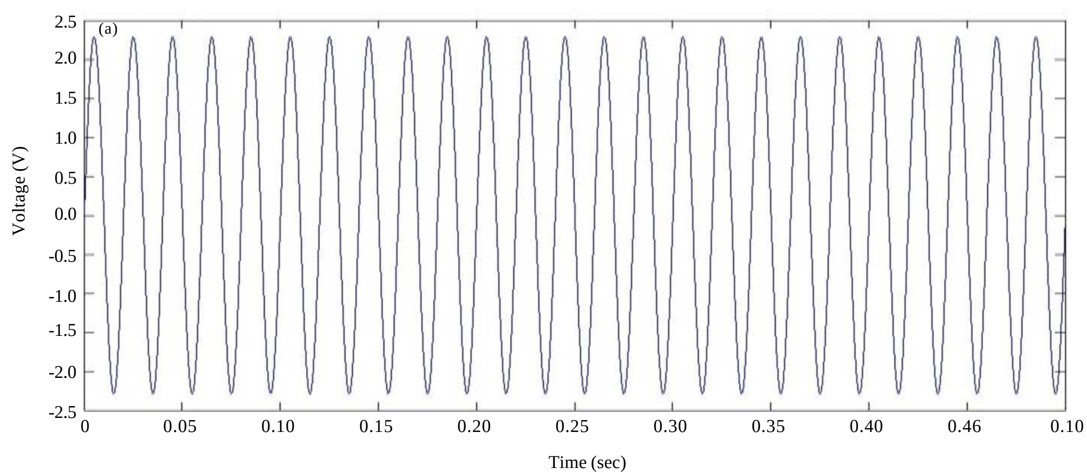

Fig. 12(a-c): Continue

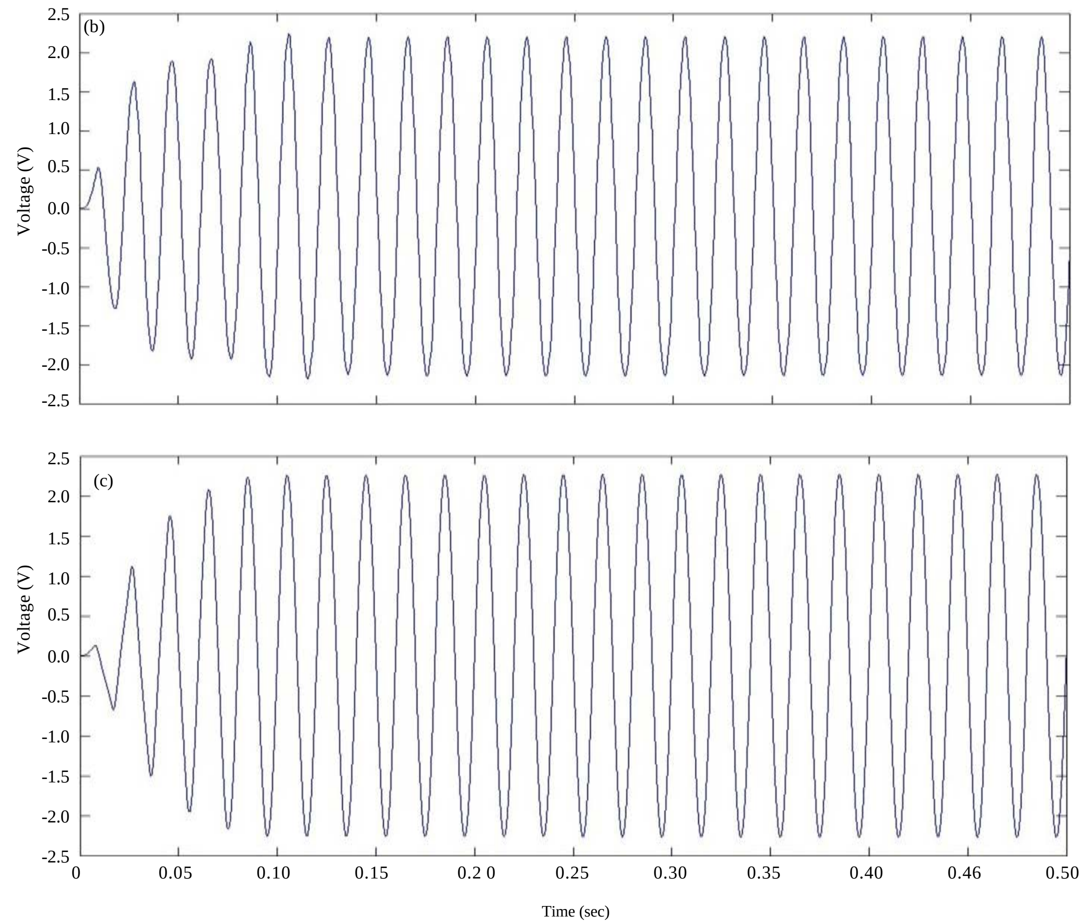

Fig. 12(a-c): Output current of proportional integral controller (a) Conventional (b) Proposed and (c) FLC

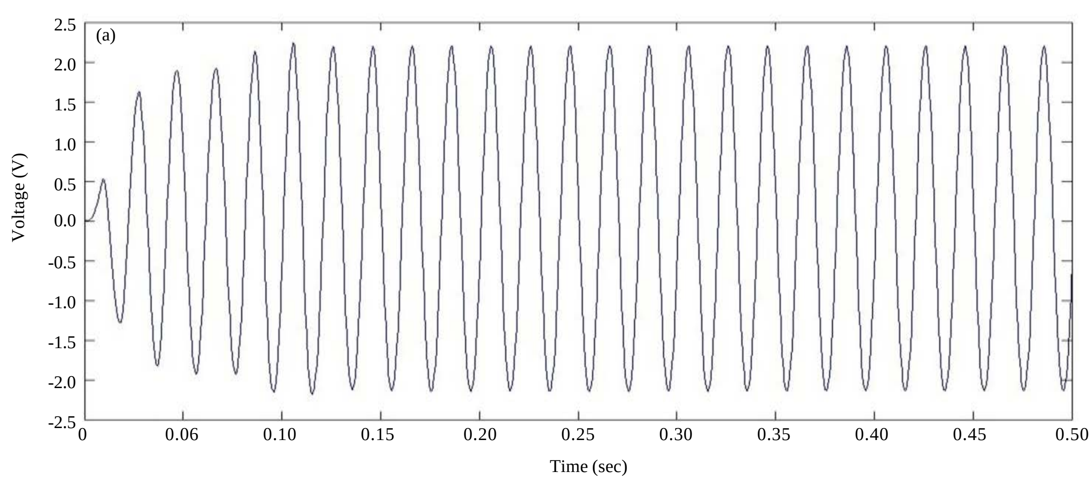

Fig. 13(a-b): Continue

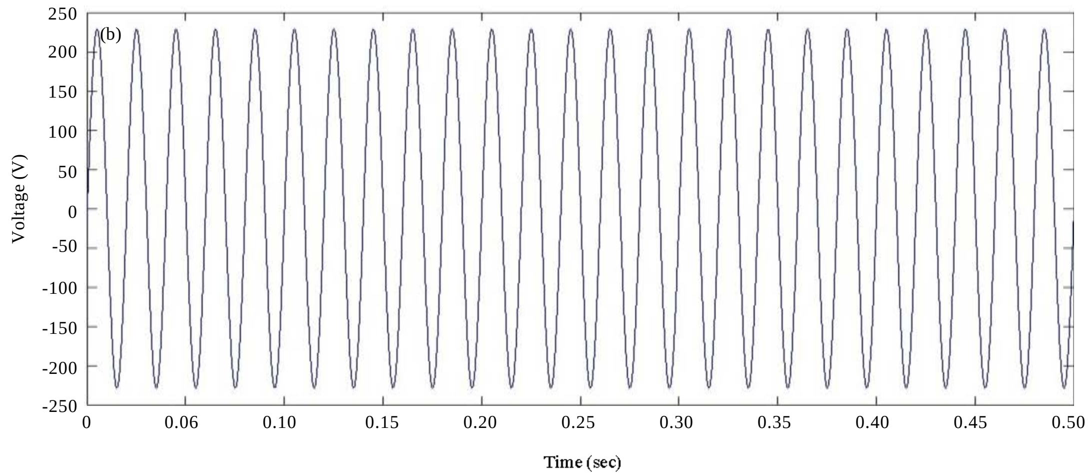

Fig. 13(a-b): Output voltage of (a) Proportional integral controller and (b) FLC

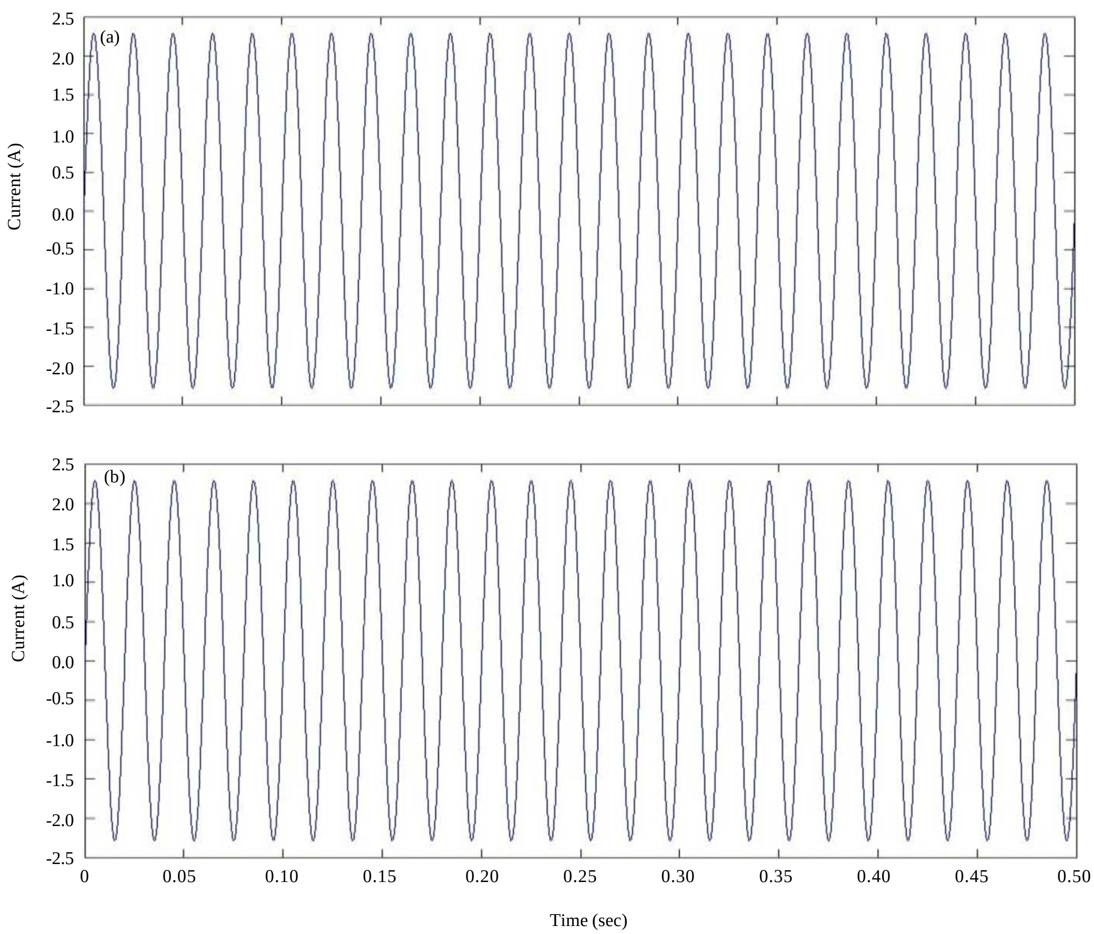

Fig. 14(a-b): Output voltage of (a) Proportional integral controller and (b) FLC

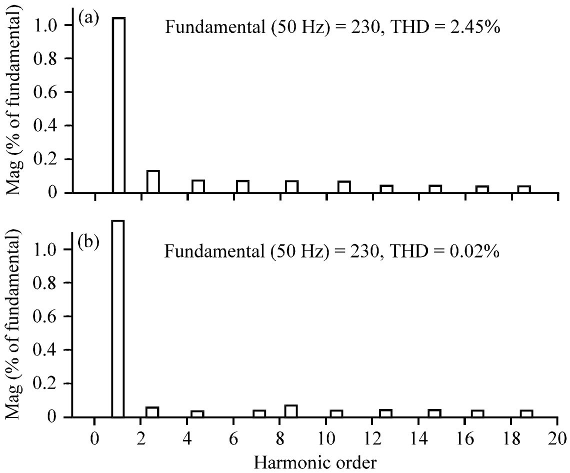

Fig. 15(a-b): FFT Analysis of grid connected CSI with (a) PI Controller and (b) Fuzzy logic controller

tuned CSI using fuzzy controller is reduced compared to PI controller.

CONCLUSION

A double-tuned CSI with PV array is simulated with PI controller and fuzzy controller in a closed loop manner in MATLAB/Simulink. The results obtained from the simulation of the current source inverter with proportional integral controller and FLC shows that the performance of fuzzy controller is best over the conventional and PI controller based converters. The double tuned CSI using fuzzy logic controller output voltage has very less total harmonic distortion. This configuration is best suitable for microgrid applications due to its reduced THD. The proposed system provides a faster response and better efficiency comparable with conventional current source inverter.

REFERENCES

Alajmi, B.N., K.H. Ahmed, S.J. Finney and B.W. Williams, 2011. Fuzzy-logic-control approach of a modified hill-climbing method for maximum power point in microgrid standalone photovoltaic system. IEEE Trans. Power Electron., 26: 1022-1030.

Alajmi, B.N., K.H. Ahmed, G.P. Adam and B.W. Williams, 2013. Single-phase single-stage transformer less grid-connected PV system. IEEE Trans. Power Electron., 28: 2664-2676.

Bashi, S.M., N. Mariun, N.F. Mailah and S. Alhalali, 2008. Low harmonics single phase multilevel power inverter. Asian J. Sci. Res., 1: 274-280.

Dasgupta, S., S.K. Sahoo, S.K. Panda and G. Amaratunga, 2011. Single-phase inverter-control techniques for interfacing renewable energy sources with microgrid-part II: Series-connected inverter topology to mitigate voltage-related problems along with active power flow control. IEEE Trans. Power Electron., 26: 732-746.

Dursun, M., 2008. A wheelchair driven with fuzzy logic controlled switched reluctance motor supplied by PV arrays. J. Applied Sci., 8: 3351-3360.

Farahani, H., 2008. Investigation of modulation index, operational mode and load type on the SHEM current source inverter. J. Applied Sci., 8: 4376-4382.

Ghasemi, R., M.B. Menhaj and A. Afshar, 2009. A Decentralized stable fuzzy adaptive controller for large scale nonlinear systems. J. Applied Sci., 9: 892-900.

Haron, A.R., A. Mohamed and H. Shareef, 2012. A review on protection schemes and coordination techniques in microgrid system. J. Applied Sci., 12: 101-112.

Kim, J.Y., J.H. Jeon, S.K. Kim, C. Cho, J.H. Park, H.M. Kim and K.Y. Nam, 2010. Cooperative control strategy of energy storage system and microsources for stabilizing the microgrid during islanded operation. IEEE Trans. Power Electron., 25: 3037-3048.

Kjaer, S.B., J.K. Pedersen and F. Blaabjerg, 2005. A review of single-phase grid-connected inverters for photovoltaic modules. IEEE Trans. Ind. Appl., 41: 1292-1306.

Mehrizi-Sani, A. and R. Iravani, 2010. Potential-function based control of a microgrid in islanded and grid-connected modes. IEEE Trans. Power Syst., 25: 1883-1891.

Petrone, G., G. Spagnuolo and M. Vitelli, 2011. A multivariable perturb-and-observe maximum power point tracking technique applied to a single-stage photovoltaic inverter. IEEE Trans. Ind. Electron., 58: 76-84.

Porasad, Y. and H. Hossein, 2008. Comparison of voltage control and current control methods in grid connected inverters. J. Applied Sci., 8: 648-653.

Ramezani, B., 2010. Speed control simulation for induction motor by multi level VSI-Fed to analyse current harmonics and selective harmonics elimination. J. Applied Sci., 10: 688-693.

Wang, F., J.L. Duarte and M.A. Hendrix, 2011. Grid-interfacing converter systems with enhanced voltage quality for microgrid application: Concept and implementation. IEEE Trans. Power Electron., 26: 3501-3513.

Wu, T.F., C.H. Chang, L.C. Lin and C.L. Kuo, 2011. Power loss comparison of single-and two-stage grid-connected photovoltaic systems. IEEE Trans. Energy Convers., 26: 707-715.

Yang, B., W. Li, Y. Zhao and X. He, 2010. Design and analysis of a grid-connected photovoltaic power system. IEEE Trans. Power Electron., 25: 992-1000.