Research Journal of Applied Sciences 9 (6): 361-368, 2014
ISSN: 1815-932X

A Standalone Solar Power Generation Using Boost Inverter by Fuzzy Logic Controller

[1]S. Rajendran and [2]S. Senthil Kumar
[1]Anna University, Chennai, Tamil Nadu, India
[2]Department of Electrical and Electronics Engineering,
Government College of Engineering, Salem, Tamil Nadu, India

Abstract: In this study, a Fuzzy Logic Controller (FLC) based technique proposed for solar power generation using boost inverter. A low dc voltage of photovoltaic array are boosted and inverted into a 220 V_{rms} ac voltage at a fundamental frequency in a single stage. A closed loop FLC technique is proposed to keep the output voltage constant barring various irradiation conditions. Generally, the sliding mode control and feedback control techniques were used for controlling the output of the boost inverter but it involves more complex control theory. The main objective is to reduce the more power stages for converting dc power in to ac power of a Standalone Solar Power Generation System consisting of a Photovoltaic (PV) panel and a boost inverter under various temperature and irradiation conditions. Hence, the proposed control technique is keep constant output voltage with variable irradiations. Therefore the proposed Solar Power Generation System has more desirable features such as low cost and minimum number of switches. The Total Harmonic Distortion (THD) generated by the proposed configuration is quite reasonable. The complete system is modeled using MATLAB/SIMULINK.

Key words: Fuzzy logic controller, dc-ac power conversion, single stage solar power generation, total harmonic distortion, configuration

INTRODUCTION

Solar power inverters are electronic circuits associated to the power inversion, control and conditioning (Mohan *et al*., 1995) the electric power. So, it is more important and critical part in a Solar Energy Power Generation System. Because inverters are inverts the variable dc output of Photovoltaic (PV) modules (Alajmi *et al*., 2013) into a constant ac voltage with a fundamental utility frequency that can be fed into the commercial electrical grid or off grid electrical network. The falling of conventional energy sources increasing of different pollutions and the ever increasing demand of the fossil fuels are motivating the engineering society to involve more investigation in the renewable power generation and the development of alternative energy sources which are less or zero pollution and eco-friendly (Bull, 2001). Many renewable sources such as wind energy, biogas and solar are now well developed as the cost effective solution for many applications. Moreover, the solar energy has become one of the most hopeful sources of energy as they are pollution less and fuel free. Beside this, solar energy is easy to adopt with existing power converters (Vrema *et al*., 2010; Wai and Wang, 2008; Akhter, 2007; Pindado, 1999). The grid connected and standalone solar power inverters are generally Switched Mode Power Circuits (SMPCs) and their outputs are derived from coupling one or more basic switch topologies. Among them, buck-boost inverter (Ma and Han, 2004), buck inverter (Sanchis *et al*., 2005), boost-buck inverter (Meza *et al*., 2005) and boost inverter (Bose, 2002) are commonly used in the Solar Power Generation System. The proposed topology shown in Fig. 1 used in this study, maintains constant voltage

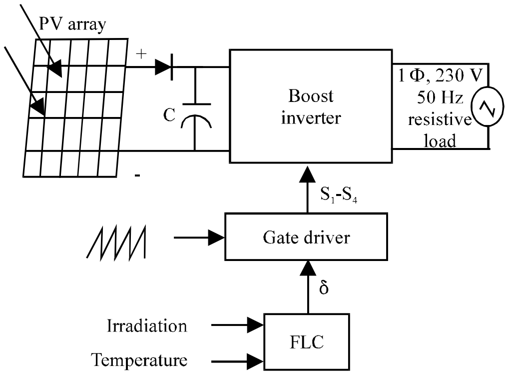

Fig. 1: The block diagram of proposed standalone solar power generation using boost inverter by fuzzy logic controller

---

Corresponding Author: S. Rajendran, Anna University, Chennai, Tamil Nadu, India under various irradiation and temperature of the solar photovoltaic cell and this study focused on a boost inverter and its control topology because of this is due to its boosting property which is achieved by a single stage. The Fuzzy Logic Control (FLC) technique (Narasimharaju *et al*., 2011) is implemented for regulating the output voltage of the boost inverter by generating appropriate duty cycle.

MATERIALS AND METHODS

Mathematical model of solar cell: For making analysis easy, a mathematical model of moderate complexity was modeled. This equivalent model as in the Fig. 2 consists of a current source and a diode connected in parallel with the current source which determines the V-I characteristics of the cell. The output of the current source is directly proportional to the light falling on the cell. A series resistance (R_{Se}) was included which give a more accurate shape between the maximum power point and the open circuit voltage. Also, the shunt resistance (R_{Sh}) was connected in parallel with the diode to achieve characteristics match. The output current of the solar cell is given by:

$$I_O = I_L - (I_d + I_{Sh}) \tag{1}$$

Where:

$$I_d = I_O\left(\exp\left[\frac{q(V_O + R_{Se}I_O)}{kT_k}\right] - 1\right) \tag{2}$$

$$I_{Sh} = \frac{V_O + I_O R_{Se}}{R_{Sh}}$$

Therefore:

$$I_O = I_L - I_O\left(\exp\left[\frac{q(V_O + R_{Se}I_O)}{kT_k}\right] - 1\right) - \left(\frac{V_O + I_O R_{Se}}{R_{Sh}}\right) \tag{3}$$

Where:

V_O and I_O = The output voltage and current of the PV
R_{Se} and R_{sh} = Series and shunt resistance of the cell (Ω)
q = Electron charge (1.6×10^{-19} C)
I_L = Light generated current (A)
I_d = Diode saturation current (A)
K = Boltzmann constant (1.38×10^{-23} J K^{-1})
T_k = Cell temperature (K)

The constants mentioned in the Eq. 1-3 were determined from the ratings of the solar PV array. For an example WAAREE PV module WS-10, a (4×10) 40 W model was used for the verification by MATLAB simulation. Thus, the mathematical model was evaluated in MATLAB using the parameters mentioned bellow WAAREE WS-10 P_{max} = 10 W, V_{max} = 17 V, I_{max} = 0.59 A, V_{oc} = 21 V, I_{SC} = 0.62 A under the STC irradiance = 1000 W/m^2 at T = 25°C and AM = 1.5.

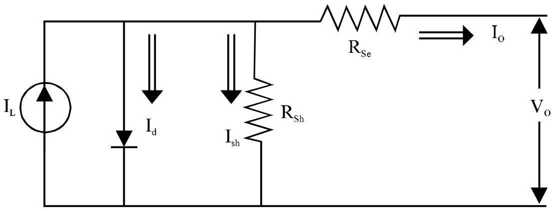

Fig. 2: Equivalent circuit of PV module

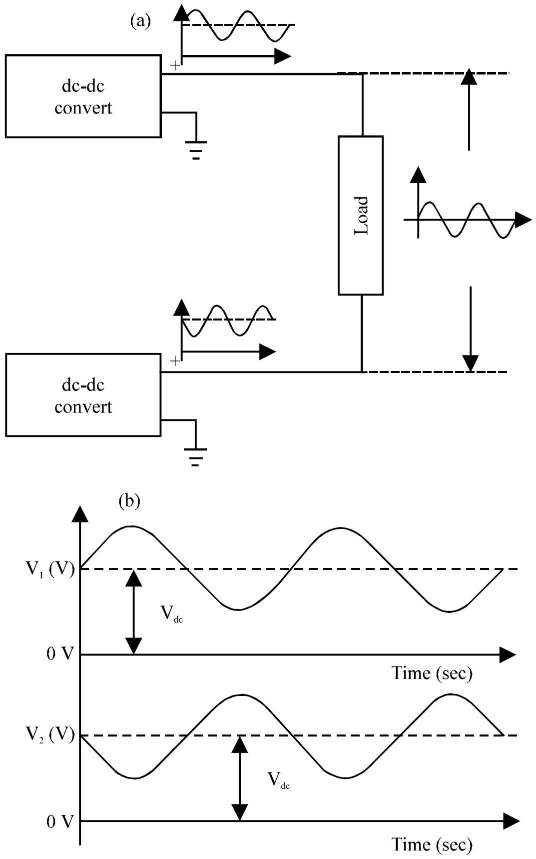

Fig. 3: a) Basic arrangement of two current bidirectional dc-dc boost converters; b) Output voltages of each dc-dc boost converters

Boost inverter: The proposed boost inverter consists of two separate current bidirectional dc-dc boost converters (Bryant and Kazimierczuk, 2005; Sanchis *et al*., 2005) shown in Fig. 3a which produces a dc-biased sine wave output so that each source only produces a unipolar voltage as in the Fig. 3b. The modulation on each converter is 180° out of phase with the other which maximizes the voltage excursion across the load. The load is connected differentially across the two converters. dc bias voltage of each converter appears at each end of the load and differential dc voltage across the load is zero with respect to ground. The main advantage of this boost inverter is the reduced number of switches, smooth sine wave of the output voltage and the dc power is boosted and inverted into ac power with a single stage. The proposed boost inverter is shown in Fig. 4. The output voltage of each converter is:

$$V_1 = V_{dc} + V_m \sin\omega t \tag{4}$$

$$V_2 = V_{dc} - V_m \sin\omega t \tag{5}$$

Voltage across the load is:

$$\begin{aligned} V_O &= V_1 - V_2 \\ &= 2V_m \sin\omega t \end{aligned} \tag{6}$$

The operation of boost inverter can be explained by modes of operation and each converter operates under two modes such as:

Mode 1: When the power switch S_1 is closed and S_2 is open as in the Fig. 4, the current i_{L1} rises quite linearly, diode D_2 is reverse polarized, capacitor C1 supplies energy to the output stage and voltage V_{C1} decreases.

Mode 2: When the power switch S_1 is open and S_2 is closed as in the Fig. 4, the supply voltage is V_{in}, the inductor current i_{L1} flows through capacitor C1 and the load, the current i_{L1} decreases while capacitor C1 recharged. The conduction mode of the converter 1 is given by:

$$\frac{V_{C1}}{V_S} = \frac{1}{1-\delta}$$

and the conduction mode of the converter 2 is given by:

$$\frac{V_{C2}}{V_S} = \frac{1}{\delta}$$

Where:

δ = The duty cycle

V_{C1} = The voltage across the capacitor of the converter 1

V_{C2} = The voltage across the capacitor of the converter 2

V_S = The input voltage to the boost inverter

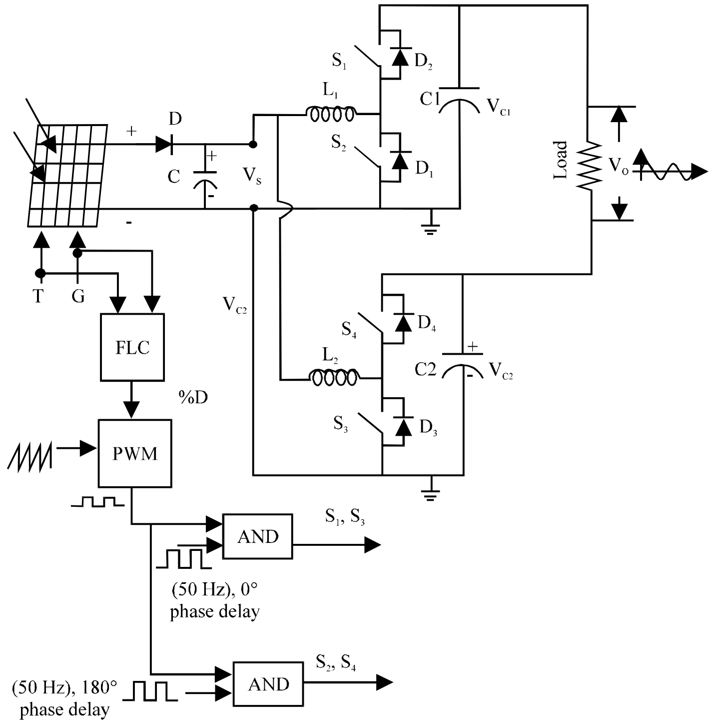

Fig. 4: Boost inverter with proposed fuzzy logic controller

Since, the two converters are 180° out of phase, the output voltage is given by:

$$
\begin{aligned}
V_O &= V_{C1} - V_{C2} = \frac{V_S}{1-D} - \frac{V_S}{D} \\
\frac{V_O}{V_S} &= \frac{2D-1}{(1-D)D}
\end{aligned}
\tag{7}
$$

Proposed control scheme for boost inverter: The dynamics of bidirectional dc-dc converters is non-linear with uncertain parameters resulting output fluctuating voltage during the operation. Due to parasitic resistances, stray capacitances and leakage inductances, the operation of converter deviates from theoretical prediction to practical. So, the converter must operate into a closed loop for giving the desired voltage output irrespective of the source and the load disturbances. All these problems are efficiently dealt within FLC and Fuzzy Control Method do not need accurate mathematical model of a plant. Therefore, it matches well to a process where the model is unknown or ill-defined (Bose, 1994, 2002). The fuzzy controller (Gupta *et al*., 1997; Mattavelli *et al*., 1997) is divided into four sections: fuzzifier, rule base, decision making and defuzzifier as shown in Fig. 5.

The fuzzifier converts crisp data into linguistic format. The output of the inference system passes through the defuzzifier wherein the linguistic format signal is converted back into the numeric form or crisp form. The various methods of fuzzy reasoning are reported in the literature (Takagi and Sugeno, 1985; Bose, 1994) such as Larsen's, Mamdani's, Tsukamot and Sugeno's O's Methods. Sugeno's Fuzzy Reasoning Method is used to obtain the inference result from a system. The solar PV module's Temperature (T) and the irradiation (G) is determined and processed through FLC. The crisp set values which are generated by FLC are fed into a Pulse Width Modulation (PWM) which ensures the PWM produces a continuous pulse with desired proper duty cycle. This continuous pulsatory signal was modified using AND Gate to match with the single phase AC load frequency 50 Hz as shown in Fig. 5.

The two inputs will be fuzzified by using normalized fuzzy sets with four triangular membership functions (MFs-input-1): Very Low (VL), Low (L), Normal (N) and High (H), (MFs-input-2): Low (L), Normal (N), High (H) and Very High (VH) as shown in Fig. 6a and b. The output variable consists of a normalized fuzzy set with triangular MF: Very Low (VL), Low (L), Normal (N) and High (H) as shown in Fig. 6c. After the fuzzification of the crisp inputs, the resulting fuzzy sets have to be compared to the rule-base. The rule base is a set of "And method-'prod' and or method-'probor" rules constructed according to the designer system knowledge and

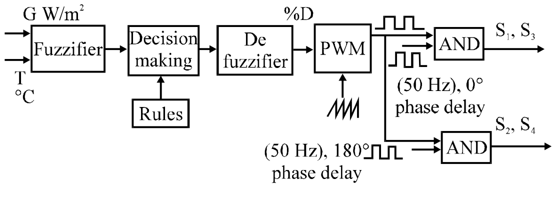

Fig. 5: Proposed fuzzy logic controller scheme for boost inverter

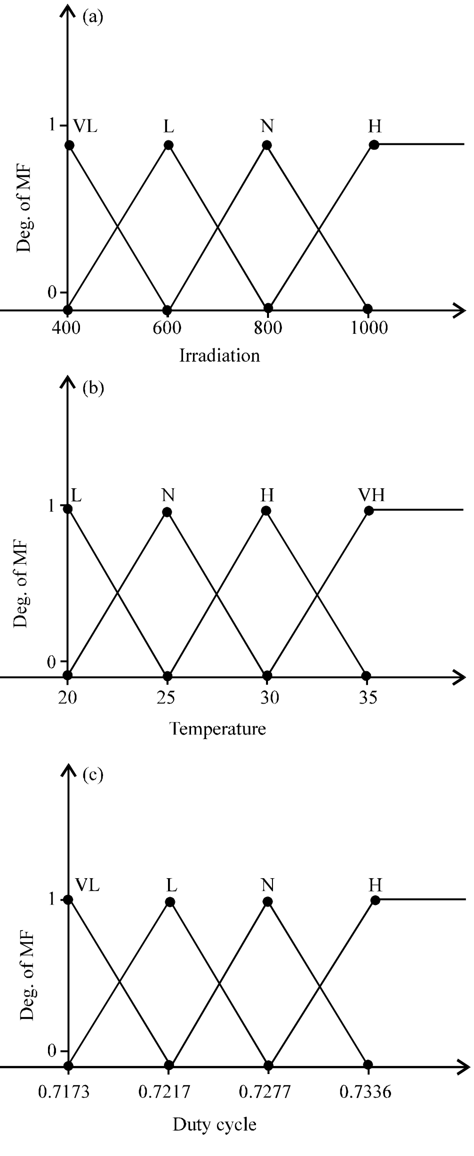

Fig. 6: a) Input membership functions of irradiation of the solar; b) Input membership functions of temperature of the solar pv panel; c) Output membership functions of duty cycle for boost inverter

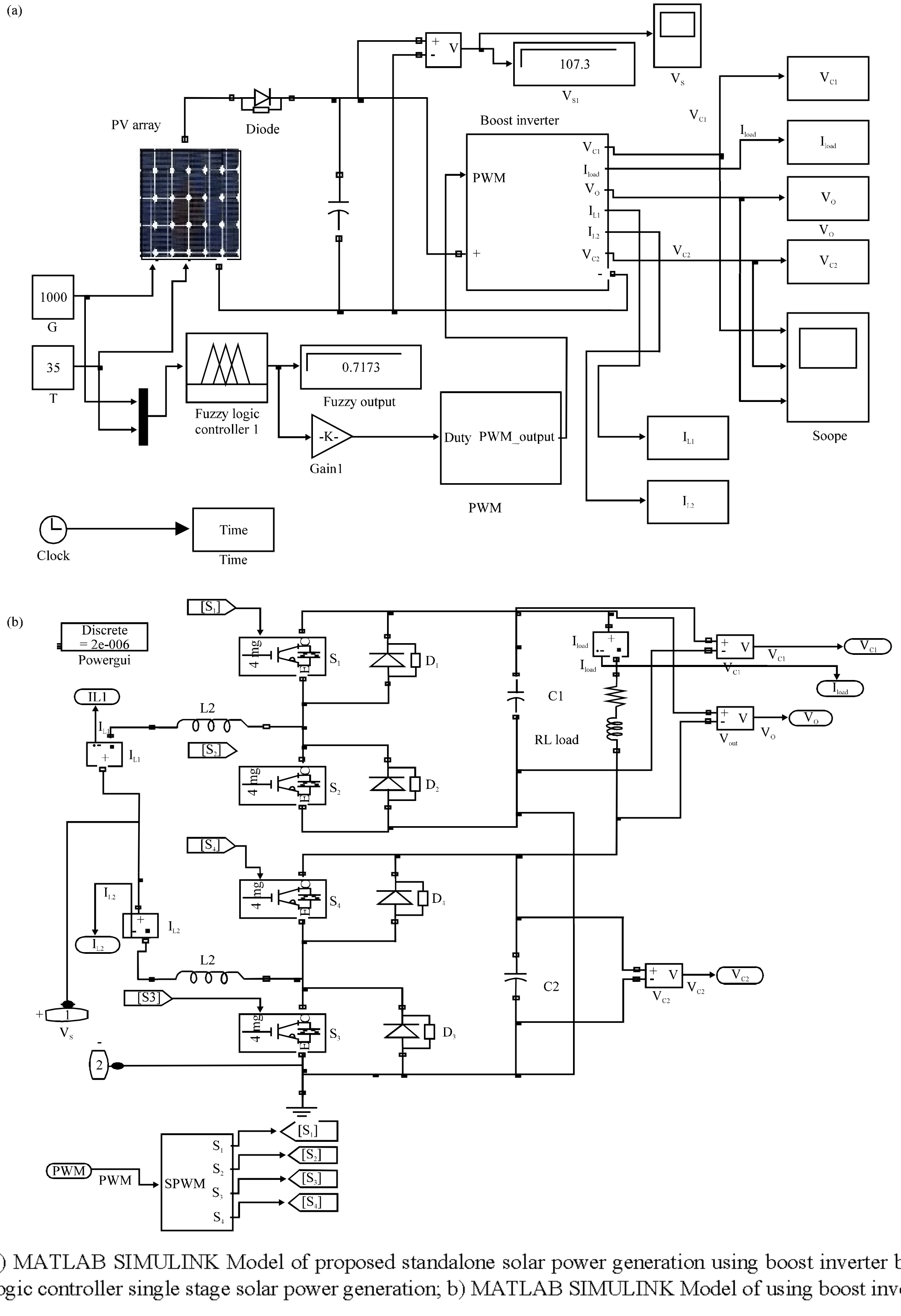

Fig. 7: a) MATLAB SIMULINK Model of proposed standalone solar power generation using boost inverter by fuzzy logic controller single stage solar power generation; b) MATLAB SIMULINK Model of using boost inverter

experience. Depending on the value of the temperature and irradiation of the solar PV panel the fuzzy out is determined as shown in the Table 1.

The last step in the FLC process is the defuzzification which takes the implied fuzzy set and transforms it back to a real continuous number or a crisp output.

They have the advantage to be robust and reasonably simple to design as they do not need the knowledge of the exact model. In the other hand, the require skill is the complete knowledge of the operation of the PV System and boost inverter by the designer. The proposed fuzzy logic controller, shown in Fig. 7, has two inputs and one output. The main advantage of this control method is to keep the output voltage constant barring various irradiations and temperatures.

Simulation model of proposed system: The proposed standalone solar power generation using boost inverter using Fuzzy Logic Controller (FLC). Figure 7a and b was developed by MATLAB SIMULINK assuming the power switches, capacitor voltage and inductors current with internal resistance Ra are ideal. The parameters are: V_{in} = 100 V, $V_O = 220\sin\omega t$, P_O = 40 W, L1, L2 = 65 mH each, C1, C2 = 100 μF each, at the duty ratio (D) of 0.7173 to 0.7336.

RESULTS AND DISCUSSION

Figure 8 shows the simulated results for the buck boost operation of the boost inverter for a non-linear (RL) load of 60 W. The obtained peak value of instantaneous AC voltage is 220 V for the input (V_S) of 100 V. The Total Harmonic Distortion (THD) of output voltage of the boost inverter (V_O) is lower than 4.5% and it is shown in study. Figure 9a shows the inductor currents I_{L1} and I_{L2} of the each dc-dc converter of the boost inverter is <8 A with a negligible current ripple which are 180° phase shifted each other. Figure 10 shows the capacitors voltages V_{C1} and V_{C2} of the each dc-dc converter of the boost inverter is 300 V and both are phase shifted by 180°. Figure 11a and b shows the percentage of total harmonic distortion of the load current as 1.87% for fundamental frequency. Table 2 shows the output voltages and THD of the boost

Table 1: Fuzzy rule base matrix

G\T	VL	L	N	H
L	H	N	L	VL
N	H	N	L	VL
H	N	L	VL	VL
VH	H	H	N	L

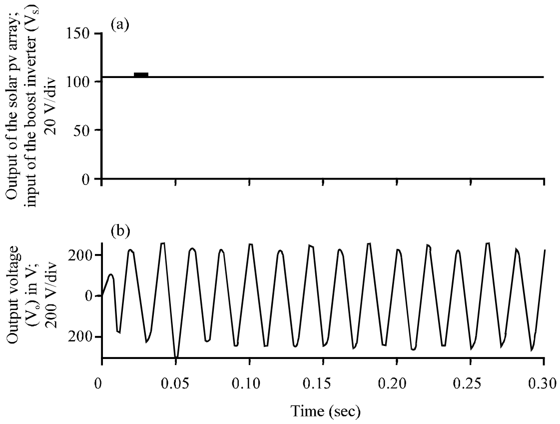

Fig. 8: a) Output of the solar PV array and input of the boost inverter (V_S) in volts, 100 V/div, 0.05 sec/div; b) Output voltage of the boost inverter (V_O) in volts, 200 V/div, 0.05 sec/div under T = 30°C, G = 1000 W/m^2

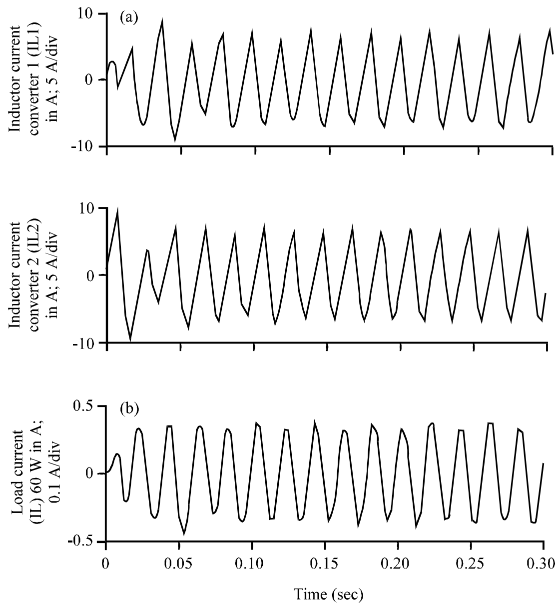

Fig. 9: a) Inductor current of the boost inverter (I_{L1} and I_{L2}) 10 A/div, 0.05 sec/div; b) Load current for 60 W RL load in Amps; 0.38 A/div, 0.05 sec/div

Table 2: Output voltages and THD of the Boost Inverter under various solar temperatures and irradiations

Solar cell Temp. (T) (°C)	Irradiance (G) (W/m^2)	Duty cycle (D)	Input voltage (V_{in}) (V)	Output voltage (V_O) (V)	THD (%)
25	1000	0.7212	104.5	230	4.58
25	800	0.7237	102.8	230	4.49
30	1000	0.7255	105.9	230	4.48
30	800	0.7255	104.3	230	4.46
35	1000	0.7173	107.3	232	4.48
35	800	0.7197	105.6	231	4.51
20	600	0.7288	99.31	228	4.33
20	400	0.7336	96.24	228	4.33

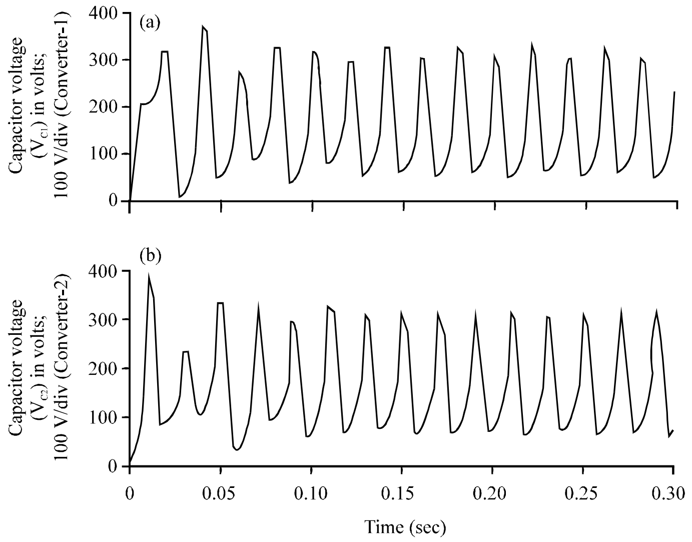

Fig. 10: Capacitors voltage of the each converter of the inverter (V_{C1} and V_{C2}) in volts, 300 V_m

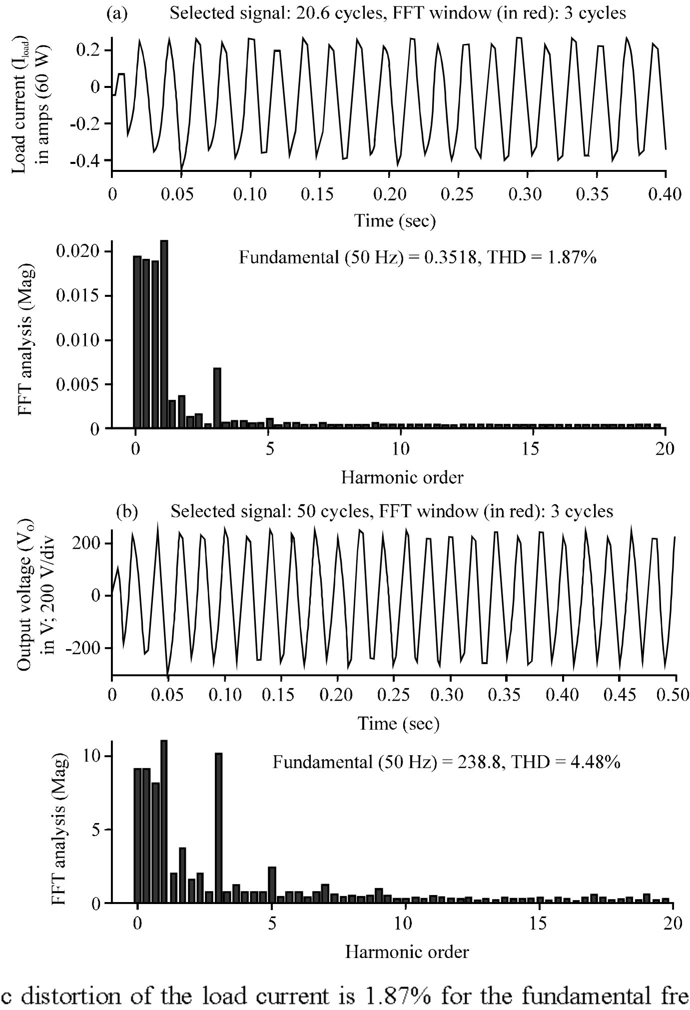

Fig. 11: a) Total harmonic distortion of the load current is 1.87% for the fundamental frequency; b) Total harmonic distortion of boost inverter for 60 W RL load is 4.48% under T = 30°C, G = 1000 W/m^2

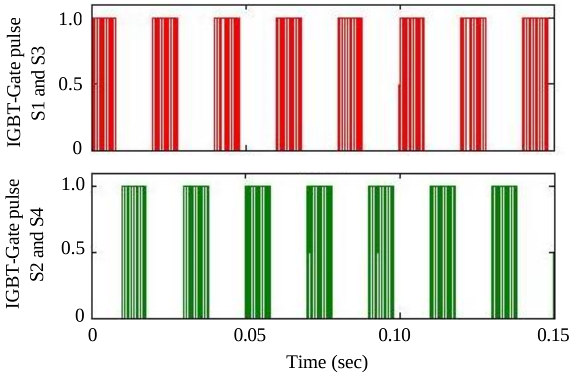

Fig. 12: Control signals for switches as 1-4 of the boost inverter with proper duty cycle generated by proposed fuzzy logic controller

inverter under various solar temperatures and irradiations. From observing the Table 2, it's clear that the proposed FLC techniques based controller is regulates and keep nearly constant output voltage of the boost inverter under various temperatures and irradiations (Fig. 12).

CONCLUSION

The design analysis of the proposed inverter has been discussed. The model of the boost inverter with FLC based control has been developed in SIMULINK environment. The inverter maintains constant output voltage with various temperature and irradiation of solar pv cell and also there is no two or more power conversion required for boosting low pv voltage and inverting the dc power into ac power. The Total Harmonic Distortion (THD) of the proposed a Standalone Solar Power Generation using Boost Inverter by Fuzzy Logic Control topology is quite reasonable. This topology is a simple concept and it regulates the output of the boost inverter by generating the appropriate duty cycle corresponding various temperature and irradiation. This control scheme is ensures the validity of the system, since it compensates the load harmonics. Such, solar power generation scheme shows feasibility, effectiveness and operational simplicity. The low cost due to the minimum number of power devices used to execute the above scheme is an additional merit.

REFERENCES

Akhter, R., 2007. A new technique of pwm boost inverter for solar home application. BRAC Univ. J., 4: 39-45.

Alajmi, B.N., K.H. Ahmed. S.J. Finney and B.W. Williams, 2013. A maximum power point tracking technique for partially shaded photovoltaic systems in microgrids. IEEE Trans. Ind. Electron., 60: 1596-1606.

Bose, B.K., 1994. Expert system, fuzzy logic, and neural network applications in power electronics and motion control. IEEE Proc., 82: 1302-1323.

Bose, K., 2002. Modern Power Electronics and AC Drives. Prentice- Hall PTR, ISBN: 9780130167439, Pages: 711.

Bryant, B. and M.K. Kazimierczuk, 2005. Modeling the closed-current loop of PWM boost dc-dc converters operating in CCM with peak current-mode control. IEEE Trans. Circuits Sys., 52: 2404-2412.

Bull, S.R., 2001. Renewable energy today and tomorrow. Proc. IEEE, 89: 1216-1226.

Gupta, T., R.R. Boudreaux, R.M. Nelms and J.Y. Hung, 1997. Implementation of a fuzzy controller for dc-dc converters using an inexpensive 8-b microcontroller. IEEE Trans. Ind. Electron., 44: 661-669.

Ma, H. and S. Han, 2004. Buck inverter with sliding mode control strategy. Proceedings of the IEEE 30th Annual Conference on Industrial Electronics Society, Volume 1, November 2-6, 2004, Busan, South Korea, pp: 592-597.

Mattavelli, P., L. Rossetto, G. Spiazzi and P. Tenti, 1997. General-purpose fuzzy controller for dc-dc converters. IEEE Trans. Power Electron., 12: 79-86.

Meza, C., D. Biel, J.Martinez and F. Guinjoan, 2005. Boost-buck inverter variable structure control for grid-connected photovoltaic systems. Proceedings of the IEEE International Symposium on Circuits and Systems, May 23-26, 2005, Tokyo, Japan, pp: 1318-1321.

Mohan, N., W.P. Robbin and T. Undeland, 1995. Power Electronics: Converters, Applications and Design. 2nd Edn., Wiley, New York.

Narasimharaju, B. L., S.P. Dubey and S. P. Singh, 2011. Performance evaluation of fuzzy logic controlled bidirectional DC to DC converter. Technia: Int. J. Comput. Sci. Commun. Technol., 3: 598-603.

Pindado, R., 1999. A modeling and closed-loop control method for DC-DC PWM converters by local average techniques. Proceedings of the IEEE International Symposium on Industrial Electronics, July 12-16, 1999, Bled, Slovenia, pp: 241-246.

Sanchis, P., A. Ursaea, E. Gubia and L. Marroyo, 2005. Boost DC-AC inverter: A new control strategy. IEEE Trans. Power Electron., 20: 343-353.

Takagi, T. and M. Sugeno, 1985. Fuzzy identification of a system and its application to modeling and control. IEEE Trans. Syst. Man Cybern., 15: 116-132.

Vrema, A.K., S.C. Kaushik and B. Singh, 2010. An isolated solar power generation using boost converter and boost inverter. Int. J. Eng. Inf. Technol., 2: 101-108.

Wai, R.J. and W.H. Wang, 2008. Grid-connected photovoltaic generation system. IEEE Trans. Circuits Sys., 55: 953-964.