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RESEARCH ARTICLE

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Design and analysis of robust fuzzy logic maximum power point tracking based isolated photovoltaic energy system

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Summary

Photovoltaic (PV) energy is highly promising because of its renewable, green, and environment-friendly nature. In this article, the design and analysis of an isolated PV system using a push-pull converter with a fuzzy logic-based maximum power point tracking (MPPT) algorithm is presented. Furthermore, DC-DC converters, along with intelligent controllers fed with MPPT algorithms, are used to ensure the maximum extraction of incident energy. The proposed methodology utilizes fuzzy logic MPPT techniques based on an isolated push-pull boost converter to optimize the power output of PV modules, as well as to achieve isolation and high DC gain for DC/AC inversion. This work also presents a single-phase inverter with fuzzy logic close loop control analysis with LCL filter design. A Canadian solar panel of 250 W is assumed in this research work, which has an open circuit voltage 59.9 V, short circuit current 5.49 A at 25°C temperature, and 1000 W/m^2 irradiance. The voltages are tracked, through the MPPT algorithm. These voltages represent a boost to 340 V DC through push-pull boost converter and are inverted up to 220 V AC through fuzzy logic voltage source inverter. In addition, a unipolar switching technique is used to remove the total harmonic distortion under linear load. The proposed methodology is simulated in MATLAB/Simulink. The simulation results verify that the proposed methodology can efficiently track the MPPT. Finally, the hardware prototype of the proposed system has been experimentally validated.

KEYWORDS

fuzzy logic control, maximum power point tracking, pulse width modulation, total harmonic distortion

1 | INTRODUCTION

Energy is the need of the modern world and there is a need to explore new means of energy, which are cheap and environment-friendly. The energy demand is increasing every year and already existing resources including thermal, hydro, nuclear, and gas are unable to meet the demand. There is a need for some alternate sources of energy that can meet the requirements of energy in the future. The energy delivered by the sun is 410 quintillion Joules/year, which is more than enough for daily usage.[1] One of the free, clean, and reliable sources of energy, whose scope is increasing rapidly, is solar energy. Utilization of naturally available solar energy does not have nor does a harmful impact on the environment and it offers an environmentally friendly source of electricity.

In order to extract the maximum power out of the incident solar energy, it is very important to track the maximum power from the photovoltaic (PV) cell in every environmental condition. The key problem in maximum power point tracking (MPPT) is to track power maximum through a DC-DC converter and an intelligent controller fed with MPPT algorithms. There are many algorithms for tracking maximum power point (MPP) but the most significant method is the fuzzy logic (FL), which is being used over the last decades. This provides faster results compared with the other conventional methods such as artificial intelligent control methods, genetic algorithm, neural networks, and constant voltage method. Neural networks use microcontrollers for the implementation of the MPPT technique on the PV system. It is also known as artificial intelligence due to its prediction ability and control strategy. There are three main units or blocks for the operation of neural networks including the input unit, processing unit, and output unit. In this method, in each unit user has an ease to add nodes according to systems requirements like current, voltage, temperature, or irradiation.[2] User can put all these variables in the input unit. These inputs are then fed into processing or hidden unit. Finally, a duty cycle signal is generated by the output unit for controlling DC-DC converters and adjust the operating voltage for gaining MPP. The proposed method is fast and robust; therefore, this is the main reason for choosing FL for MPP in this research.

Many types of DC-DC converters have been reviewed depending on the accessibility of the transformer and applications of required power ratings. The objective of using DC-DC converters is to step up or step down the DC voltage magnitude or vary its polarity. Broadly classifying, two types of DC-DC topologies exist in the literature: first is power converter with one switch topology and the other one is power converter with two switch topology.[3] Power converter with one switch topology is mostly used for the conversion of low power and power converter with two switch topology is used for the conversion of high power and this topology is also used for isolation purposes.[4] Boost converter step-ups DC input voltage by stepping down current and keeping the power constant on both input and output side. It is a member of the switched-mode power supply's family, which consist of a diode, transistor, capacitor, and an inductor. Sometimes, filters are added on both the load side and supply side for reducing ripple voltage.[5] The boost converter is widely used in PV systems to extract maximum energy of the PV array in terms of electrical power and also to match the voltage level of the electric grid. Due to the use of a single switch in its circuitry, it contains high efficiency and tracks MPP under varying temperature and irradiance.[6] In Reference 7, three methods including incremental conductance (IC), Perturb & Observe (P&O), and pulse width modulation (PWM) are deployed to grid-connected PV system. The exploitation of IC, P&O, and PWM result in total harmonics distortion (THD) of 15.4%, 14.4%, and 20.6% respectively. But, in our proposed model it is reduced to less than 2%.

In proposed model, the solar energy that is tracked through the fuzzy logic controller (FLC) is boosted through DC-DC isolated converter, which consists of a transformer that provides the isolation as well as a proper boost in voltage. The boosted DC energy is inverted into AC using a sine wave inverter and LCL filter. Generally, two types of inverters are being used, that is, voltage source inverter (VSI) and current source inverter (CSI), for photovoltaic applications. However, the THD associated with these inverters are relatively higher; therefore, the proposed fuzzy logic voltage source inverter is used in the current research. The proposed fuzzy logic voltage source inverter is capable of producing different types of output such as square wave, modified square wave, and pure sine wave depending on the requirements of application.

For obtaining the maximum power output through PV systems, different types of isolated and nonisolated converters are used where each converter has different merits and demerits. In this regard, authors in References 8,9 tested the tuning circuits of diffident setups to improve the MPP with low oscillation, low ripple, low overshoot, and good rapidity in slow and fast-changing atmospheric conditions. In this article, the isolated boost converter is used with the high-frequency transformer, which provides the isolation between the input side and output side and high conversion ratio. In the end, the PV power is inverted into 220 V AC by employing pure sine wave inverter. Through the design and implementation of a high-frequency blocking LCL filter the over-all THD is reduced. Furthermore, the unipolar switching technique with FLC is used to eliminate the THD.

2 | LITERATURE REVIEW WITH BACKGROUND CONCEPTS

The speedy increase in the demand for energy and sudden change in environmental condition leads the global world to seek for novel sources of energy that is cheaper and compatible compared with conventional fossil fuel-based sources of energy. The current research shows that alternative sources like solar energy, geothermal, and wind have become important for the generation of electricity.[10] The important thing about solar energy is that the solar irradiance incident upon solar cells which is the light energy is transformed into pure electrical energy and can be directly used. These solar cells are made of silicon and the output of an individual cell is so much low therefore these cells can be connected in series or parallel for gaining the desired output voltage.

The solar energy gained by the panel depends on the different factors like temperature and irradiance. By changing these factors, the output of the solar cell is also changed; therefore, it is very important to track the point at which the power gained is maximum, that point is called maximum power point. Solar cells normally have low efficiency but the efficiency can be increased by tracking the MPP and by connecting high load at the output of solar panel. The power amount that is obtained from a solar cell is also dependent on the photovoltaic voltage. Normally we observe the maximum point, voltage-current (V-I), and power (P-V) curves at specified temperature and irradiance.

In Reference 11, different techniques were discussed for MPPT such as fractional open-circuit voltages, fractional short circuit current, curve fitting, IC, and P&O techniques. All these techniques are simple and easy to implement but they have different problems.[12] In existing techniques, P&O and IC techniques are mostly used because of their simplicity and have less time to track the MPPT. Whenever the weather condition change suddenly then MPP change accordingly and perturbation takes place in maximum power point. During this condition, P&O technique gives the wrong MPP, and sometimes it does not give any MPP. For removing this problem IC technique was developed. It takes two samples of current and voltage for measuring the MPP. This technique has a complex algorithm in terms of calculation and also results in low efficiency, and high cost. In Reference 13, the P&O and incremental conductance MPPT algorithms are compared and their simulation results are presented. These results show the IC method has better performance than P&O algorithm. Furthermore, IC algorithms improve the dynamics, steady-state performance, and efficiency of the PV system.

From 2007 to 2017[10] new techniques were introduced such as adaptive perturbation and observation, artificial neural network, genetic algorithm, particle swarm optimization, and fuzzy logic. All these techniques are very complex and not give the accurate MPP at every precise moment of time except the fuzzy logic and easy to use.[14] The comparison of different MPPT techniques is given in Table 1.

Alekesy Trubitsyn introduced a high-efficiency DC to AC converter in 2010[15] for the photovoltaic system. For PV application, he presented a single-phase microinverter and multidimensional technique used for high efficiency. This inverter provided the modified sine wave but had a little amount of harmonic distortion and was not efficient for sensitive devices like motors, and so on. In Reference 16 for the protection of power substation, an inverter system and control were introduced by Rickard Ekstorm. This was without the feedback controller and used sine pulse width modulation when the load was applied this displayed a high voltage drop. In 2004[17] a multilevel H-bridge inverter for eliminating harmonic using resultant theory and polynomial systematic. The fundamental multilevel switching technique is used power electronic switches. In this inverter, multilevel DC voltages were used for producing the sine wave voltage.

In Reference 18, a four-leg voltage source inverter was proposed for high power by using control strategies. The author used the conventional controller; therefore, there were some harmonic influences in fans and sound devices. In Reference 19, a PWM voltage source inverter was introduced for the excitation of a single-phase induction generator. The authors simulated the single-phase generator with PWM inverter using the device model on MATLAB. All the above converters have problems in some applications such as these converters produce so much harmonic distortion in loads resulting in high power dissipation. The fuzzy logic controller is more convenient compared with the conventional controller. It can easily handle the nonlinearity and work with imprecise inputs, in other words, it is more robust.[20] Although fuzzy MPPT is well established but we have modeled a fast response algorithm that can track the maximum power in 0.03 seconds.

TABLE 1 Comparison of different MPPT techniques

MPPT techniques	Speed convergence	Complexity of implementation	Periodic tuning	Sensed parameters
Perturb and observe	Slow	Low	No	Voltage
Incremental conductance	Slow	Medium	No	Voltage current
Neural network	Fast	High	Yes	Varies
Fuzzy logic control	Fast	Low	Yes	Voltage current

3 | PROPOSED METHODOLOGY

In proposed method, the PV system is used as an energy source and this energy is boosted through push-pull boost converter, while this push-pull boost converter also provides the isolation between the input side and the output side through the transformer. Furthermore, a high-frequency transformer and two switch topology are used to feed the transformer as shown in Figure 1. In this converter, 40-kHz switching frequency is used to switch the switches and a 500-W converter is designed to transfer the power. Fuzzy logic based MPPT is applied to extract the power at every precise moment of environmental condition and the Mamdani method is used for the defuzzification of fuzzy rules.

Through the transformer, DC output voltage of the photovoltaic system is boosted to 330 V DC and then this DC voltage is converted into RMS 220 V AC through the fuzzy logic power inverter and H-Bridge inverter. This inverter is designed at 10 kHz switching frequency and the fuzzy logic controller is used to remove the lower order harmonics. For removing the higher order harmonic, LCL filter is designed. The fast Fourier transform analysis of the proposed methodology is also presented through the MATLAB power graphical user interface (GUI) block as shown in Figure 19.

3.1 | Fuzzy logic MPPT flow chart

The fuzzy logic MPPT first senses the voltage and current in each instant K then calculates the power. This power is compared with the previous instant power for obtaining the change in power as well as the current is also compared with the previous current for obtaining the change in current. This change in power is divided by the change in current for obtaining the error. Then this error is compared with the previous error, for obtaining the change in error. Error and change in error are basically the inputs of the fuzzy logic controller as per the following equations.

$$e(k) = \frac{\triangle P(k)}{\triangle I(k)} = \frac{P(k) - P(k-1)}{I(k) - I(k-1)}, \tag{1}$$

$$\triangle e(k) = e(k) - e(k-1). \tag{2}$$

The fuzzy logic controller consists of three components: fuzzification, inference, and defuzzification as shown in Figure 2. The fuzzification component receives the data according to the user to define charts such as zero, negative big (NB), and positive big (PB). In the inference component, different techniques are used for proper output, mainly the Mamdani inference technique is used here with fuzzy rules. The defuzzification component gives the final output value after the defuzzification process. The center of gravity (COG) method is used here for the defuzzification process. Finally, the fuzzy logic controller sets the duty cycle for driving the push-pull converter switches.

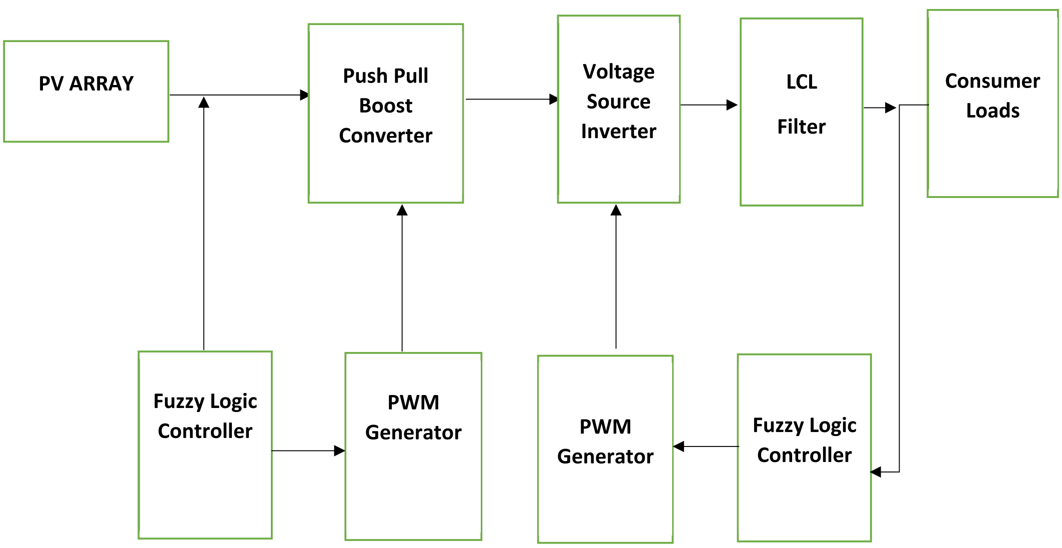

FIGURE 1 Block diagram of the proposed methodology

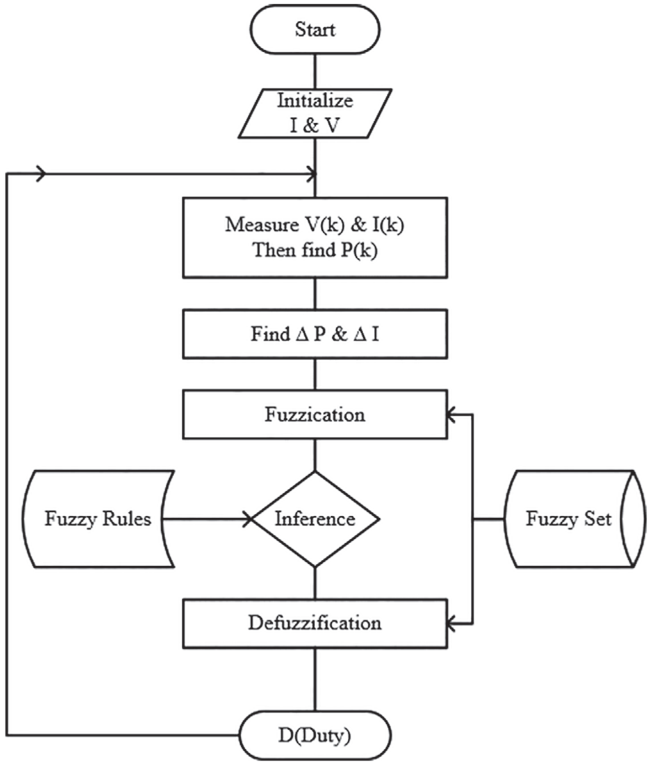

FIGURE 2 Fuzzy logic MPPT flow chart

3.2 | Proposed push-pull boost converter

The selected converter is shown in Figure 3. Selection is based on isolation between input and output side, maximum efficiency, the minimum number of switches, and simplicity of configuration. The converter has the main advantages such as this will always provide the constant input current, high voltage conversion, and low conduction loss of switches.

When both switches are in off position then the voltage across these switches is double compared with the other positions. Due to this double voltages, overstress may occur across these switches. To overcome this overstress the transformer tapping voltages are set according to the Equation (3).

$$V_{\mathrm{ct}} \cong 1.05 \times V_{\mathrm{in,max}}. \tag{3}$$

During the dead time when both switches are in OFF position, the current fluctuation of inductor increases in a linear mode of operation and V_{in} as provided in Equation (4).

$$V_{\mathrm{in}} = \frac{2L \triangle I}{t_{\mathrm{off}}}. \tag{4}$$

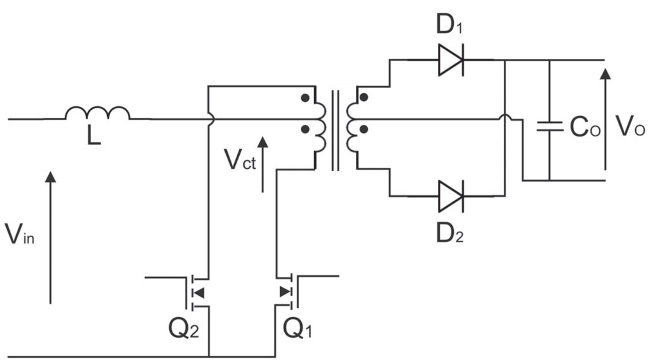

FIGURE 3 Push-pull boost converter

Now, when only one switch is ON then the voltage of the secondary side of the transformer

$$V_{ct} = V_{in} + \frac{2L \triangle I}{t_{on}}. \tag{5}$$

Hence

$$V_{ct} = V_{in} + \frac{V_{in} \times t_{off}}{t_{on}} = V_{in} \times \frac{1}{2(1-D)}. \tag{6}$$

The efficiency of the input current of the inductor can be explained by Equation (7).

$$\eta = \frac{P_o}{I_i \times V_d}. \tag{7}$$

The inductor size is selected carefully, a varying value of inductor current may cause the converter to operate in the discontinuous mode and the very high-value inductor may cause an increase in the size and weight of the converter.

$$\triangle I = xI_i. \tag{8}$$

For optimal operation, the range of x lies between $0.05 \le x \le 0.3$.

$$V_{in} = V_{ct} \times 2(1-D) = \frac{2L \triangle I}{t_{off}}. \tag{9}$$

Rearranging the equation

$$L \triangle I = V_{ct} \times 2(1-D) \times (D - \frac{1}{2})T. \tag{10}$$

Final inductor value is given by Equation (11):

$$L = \frac{V_{ct}}{16 \times f_s(\triangle I)_{max}}. \tag{11}$$

The output capacitor value is selected as given in Equation (12)

$$C_o = \frac{P_o(2D-1)}{4y \times V_o^2 \times f_s}, \tag{12}$$

where y is DC ripple voltage and its allowable threshold value is 3%. The transformer primary voltage is known and the secondary voltage is the rated output voltage and transformer turn ratio can be expressed as given in Equation (13).

$$n = \frac{2V_o(1-D)}{V_{in}}. \tag{13}$$

3.3 | Filter design parameters

Inverters are used to invert the DC power into AC power in a grid-connected system or in a standalone mode and different techniques are used for this purpose. In every inverter, the filter is necessary for producing neat and clean output power. A single inductor connected in series can be used for these purposes but the size of this inductor would be increased and also this cannot eliminate the total harmonic content and distortion factor. Commonly, an LCL filter can be used in place of bulky inductor for smoothing the output current from VSI. The simulation parameters of the LCL filter are shown in Table 2. The filter value is referred to base impedance and capacitance as given.[21]

$$Z_b = \frac{E_n^2}{P_n} = \frac{V_o^2}{\text{Power}}. \tag{14}$$

TABLE 2 LCL filter parameters used in the simulation

LCL filter parameters	Values
C_b	1 mF
C_f	15 μF
L_1	3350 μH
L_2	100 μH
R_f	2 Ω

$$C_b = \frac{1}{wgz_b}. \tag{15}$$

For a design capacitance of a filter, the allowable power variation is 5%. The base impedance is adjusted as follows $C_f = 0.05C_b$ and L_1 inverter side inductor has 10% ripple of rated current, then L_1 can be expressed as in Equation (16).

$$L_1 = \frac{V_{\text{dc}}}{16f_s \triangle I_{\text{Lmax}}}, \tag{16}$$

where $\triangle I_{\text{Lmax}} = 0.1I_{\text{max}}$ and $I_{\text{max}} = P_n/V_o$. Also L_2 is calculated with the formula

$$L_2 = \frac{\sqrt{\frac{1}{K_a^2}} + 1}{C_f ws^2}. \tag{17}$$

where K in Equation (17) is the attenuation factor which is considering as $K_a = 0.2$. The capacitor value is calculated by the formulas

$$w_{\text{res}} = \frac{\sqrt{L_1 + L_2}}{L_1 \times L_2 \times C_f}, \tag{18}$$

where $C_f = \frac{0.01}{0.05C_b}$

An R_f is a series resistance connected with a capacitor to avoid the resonance and is calculated by the formula[21].

$$R_f = \frac{1}{3w_{\text{res}} \times C_f}. \tag{19}$$

4 | SIMULATION RESULTS

In this research, the push-pull converter model is simulated for 0.3 seconds but it tracked the MPP at a very small amount of time through a fuzzy logic controller at temperature 25°C and irradiance 1000 W/m^2 as shown in Figure 4. Furthermore, Figure 6 shows the MPPT at different irradiance. The P-V characteristic curves are also shown in Figure 5.

The push-pull current is fed to DC-DC boost converter, which consists of the high-frequency transformer with two center-tapped winding. One series inductor and two switches are connected to the primary winding. Two diodes are connected to the secondary winding. These switches operate in following four states.

State 1

In this state, both switches are on in this condition and the flux produced in two winding is canceled out due to its opposite polarity and the transformer cannot sustain any voltage and appears shorted. During this interval, the series inductor is charged and no voltage is transferred to the secondary winding.

State 2

In this state, the switch 1 is in ON state, during this the primary voltage is transferred to the secondary winding. Also, the diode D1 is ON and current flows through this diode and charges the capacitor.

State 3

In this state, again both switches are ON and no voltage is transferred to the secondary winding. During this the charged capacitor is discharged through the connected load.

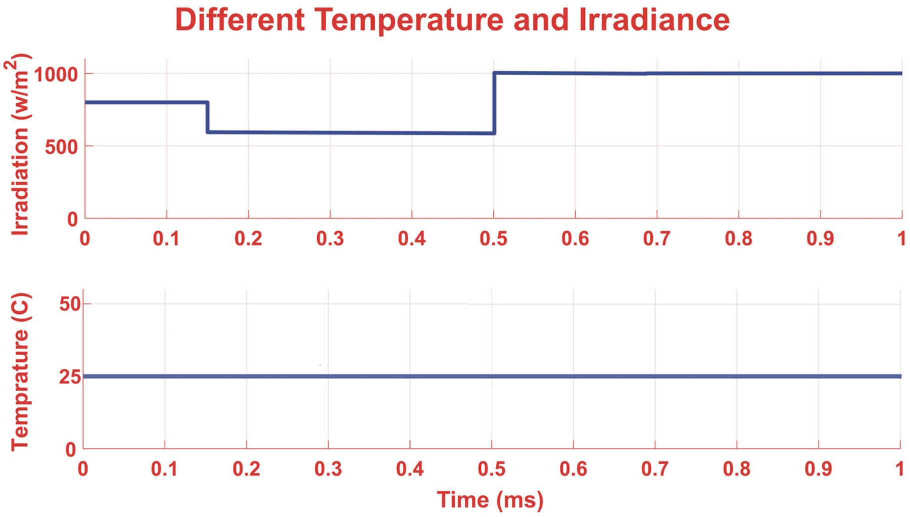

FIGURE 4 Irradiance and temperature

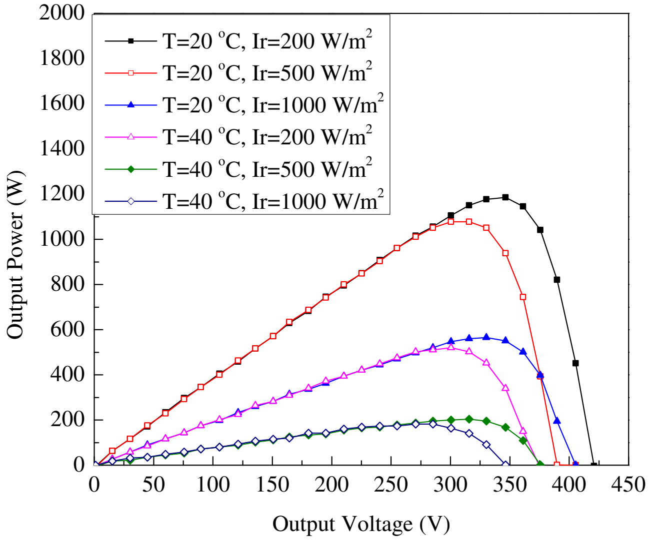

FIGURE 5 I-V characteristics

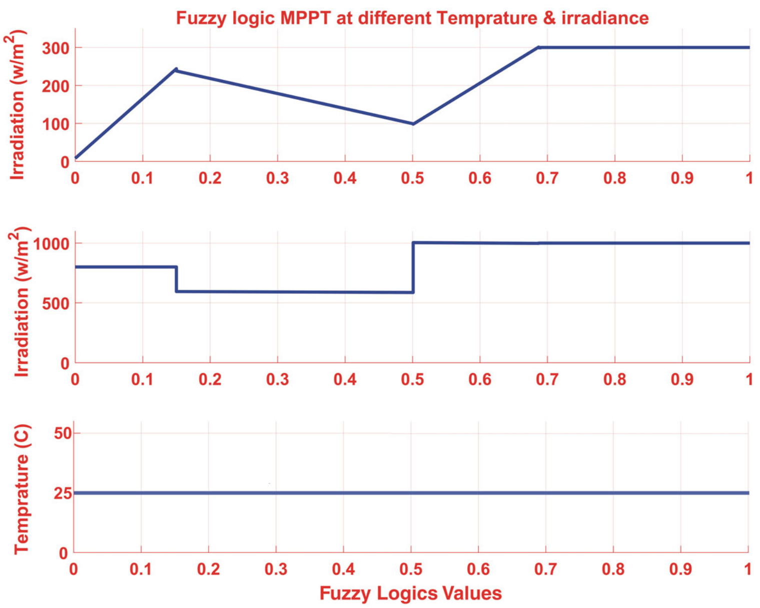

FIGURE 6 Fuzzy logic MPPT at different irradiance

State 4

In this state, the switch 2 is in ON state than diode D2 is ON and current flows through this diode and charges the output capacitor. This process repeats until the desired output is attained. The fuzzy logic membership functions designer, fuzzy logic rule editor, fuzzy logic membership function input error, membership function change in error, membership function output, fuzzy logic PWM, inductor current, push-pull transformer output voltage, and push-pull converter output are shown in Figures 7-14, and 15, respectively.

Two inputs are taken as fuzzy inputs to design fuzzy MPPT as shown in Figure 7. The inputs are input error and change in error due to irradiation and temperature fluctuations. The fuzzy rules of both inputs are shown in Figure 8. The membership functions of input error and change in error are shown in Figures 9 and 10, respectively, while the membership function of output can be seen in Figure 11. The logic of these membership functions is listed in Table 3. PWM generator used in the simulation is shown in Figure 12. The inductor current has some ripple as shown in Figure 13. This effect finishes with the fuzzy controller of the inverter and LCL filter. The boosted DC voltage is 340 V as shown in Figure 14. The converter output which delivers the boosted voltage to the inverter is shown in Figure 15. The fuzzy rules given in Table 3 are used for the desired MPP of push-pull converter PWM.

In sine wave power inverter, 340 V is applied through the push-pull DC-DC boost converter and these voltages are converted into 220 V RMS AC voltages and fuzzy logic controller, while the unipolar switching technique is used to obtain the pure sine wave with very low THD value.

The fuzzy logic-based controller is applied as feedback to the controller. This controller has two inputs: error (e) and change in error (△e). The output voltage is sensed and these voltages are compared with the reference 220 RMS AC

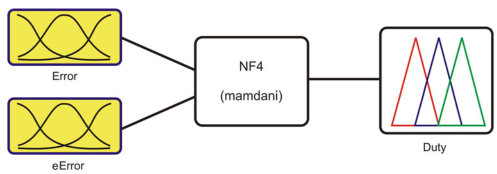

FIGURE 7 Fuzzy logic designer

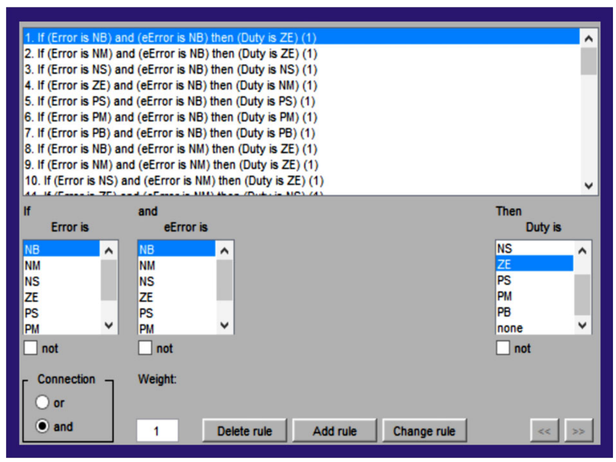

FIGURE 8 Fuzzy rules editor

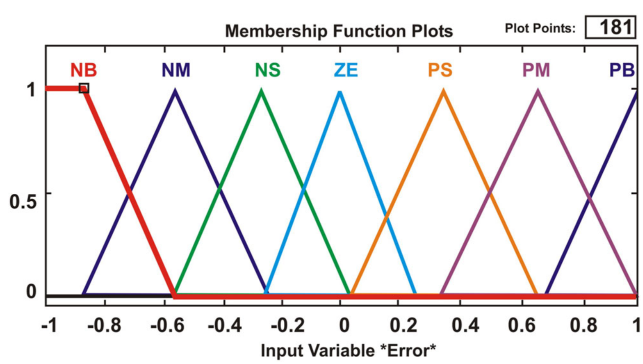

FIGURE 9 Membership function input error

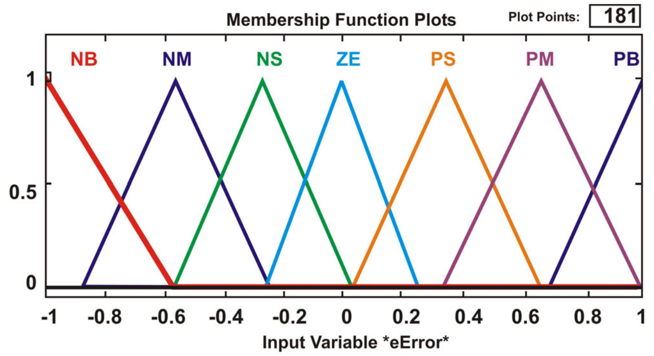

FIGURE 10 Membership function change in error

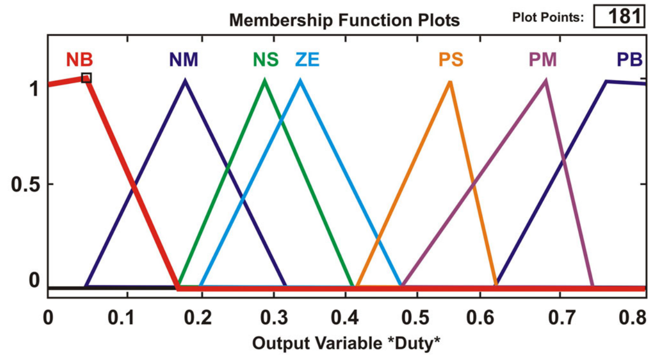

FIGURE 11 Membership function output

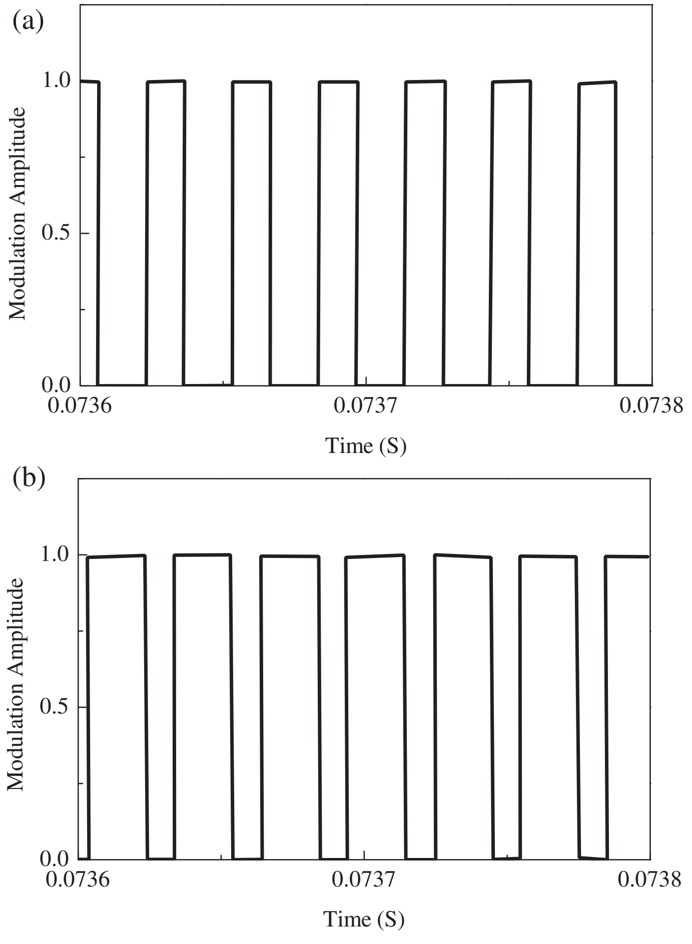

FIGURE 12 Fuzzy logic PWM

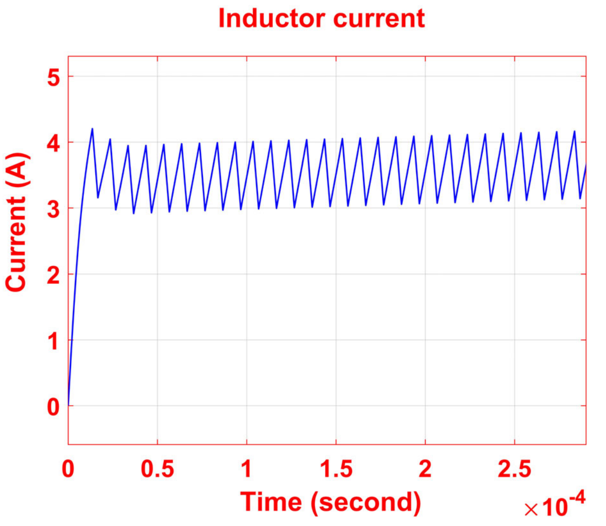

FIGURE 13 Inductor current

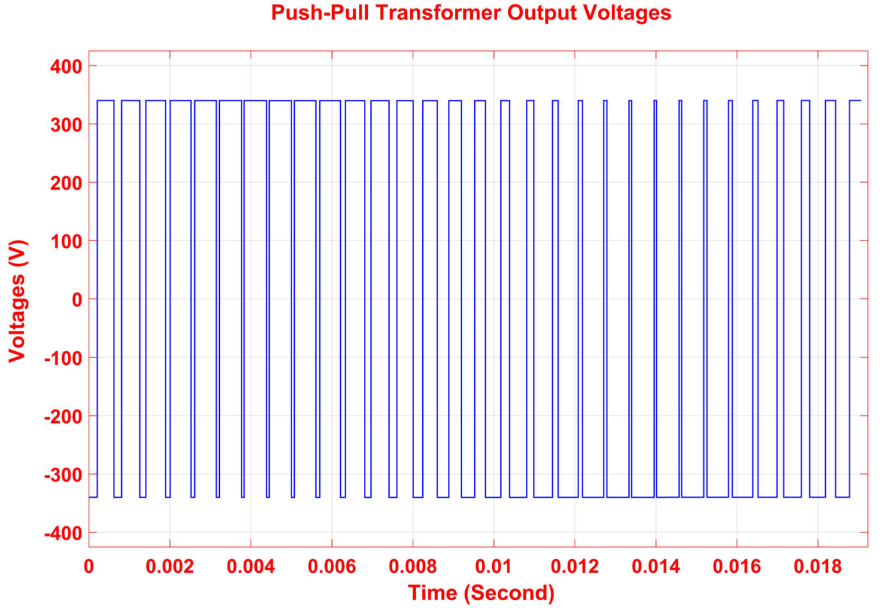

FIGURE 14 Push-pull transformer output voltages

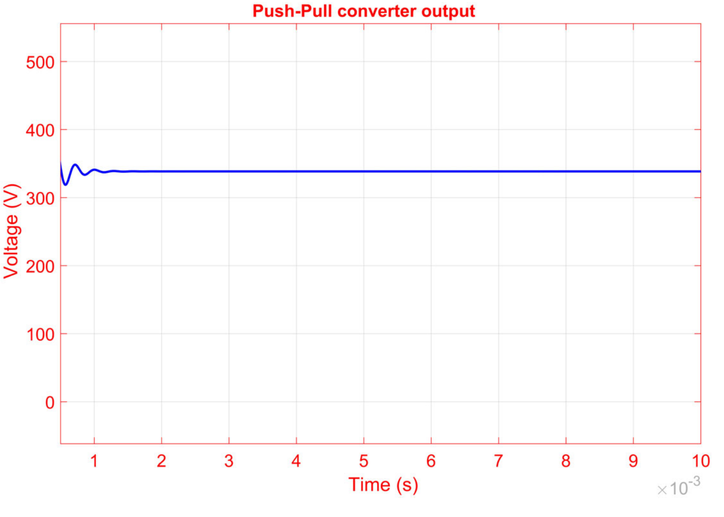

FIGURE 15 Push-pull converter output

CE, E	NB	NM	NS	ZE	PS	PM	PB
NB	ZE	ZE	ZE	NB	NB	NB	NM
NM	ZE	ZE	ZE	NS	NM	NM	NM
NS	NS	ZE	ZE	ZE	NS	NS	NS
ZE	NM	NS	ZE	ZE	ZE	PS	PM
PS	PS	PM	PM	PS	NZ	ZE	ZE
PM	PM	PM	PM	ZE	ZE	ZE	ZE
PB	PB	PB	PB	ZE	ZE	ZE	ZE

TABLE 3 Fuzzy logic rules for push-pull converter

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	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

TABLE 4 Fuzzy logic rules for inverter

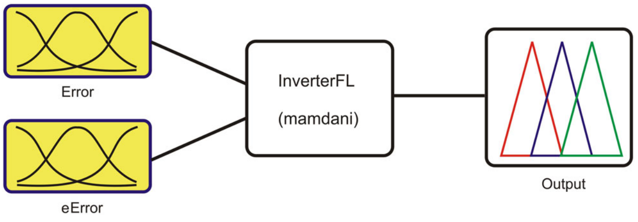

FIGURE 16 Fuzzy logic inverter designer

voltages for obtaining the error (e) and then this error (e) is integrated for obtaining the change in error (e), these are basically the inputs of FLC, which are shown in Table 4. The fuzzy logic-based controller uses the fuzzy rules and gives the smooth AC output voltages with respect to the reference voltages. By applying the fuzzy tool in MATLAB the sine wave power inverter with fuzzy input and output membership function is shown in Figure 16.

The output voltages have a low THD value as shown in Figure 18, while high THD value of voltage without filtering can be seen in Figure 17. The output voltage of the inverter is sinusoidal with the 50 Hz output frequency, where the TDH

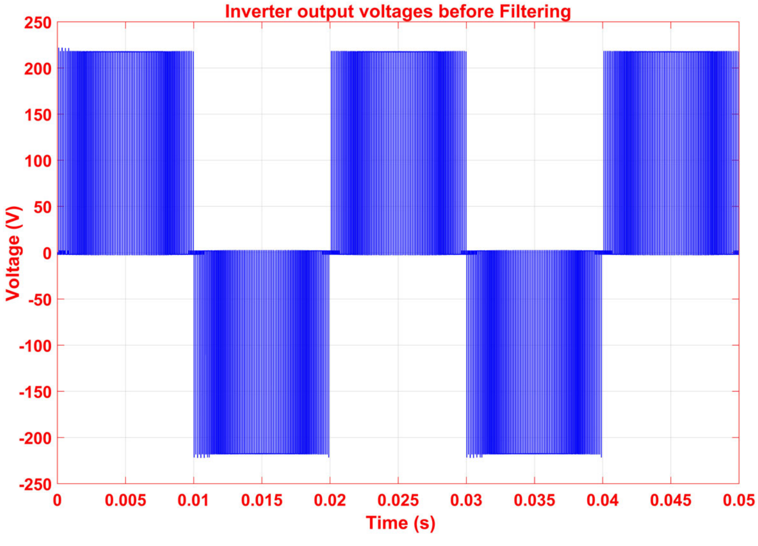

FIGURE 17 Inverter output voltages before filtering

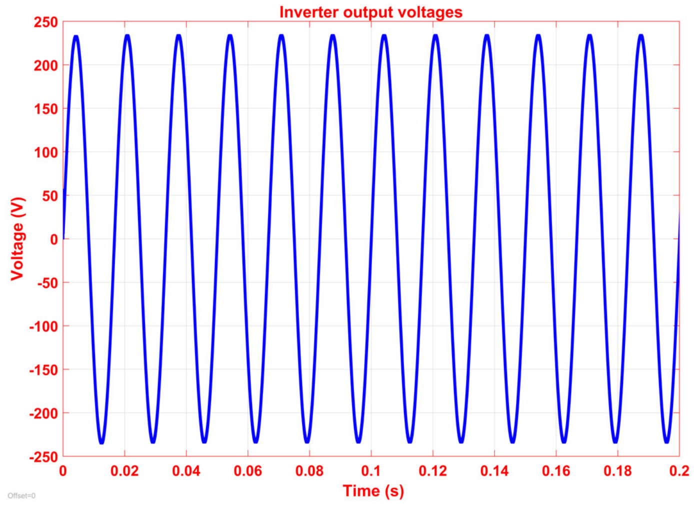

FIGURE 18 Inverter output voltages

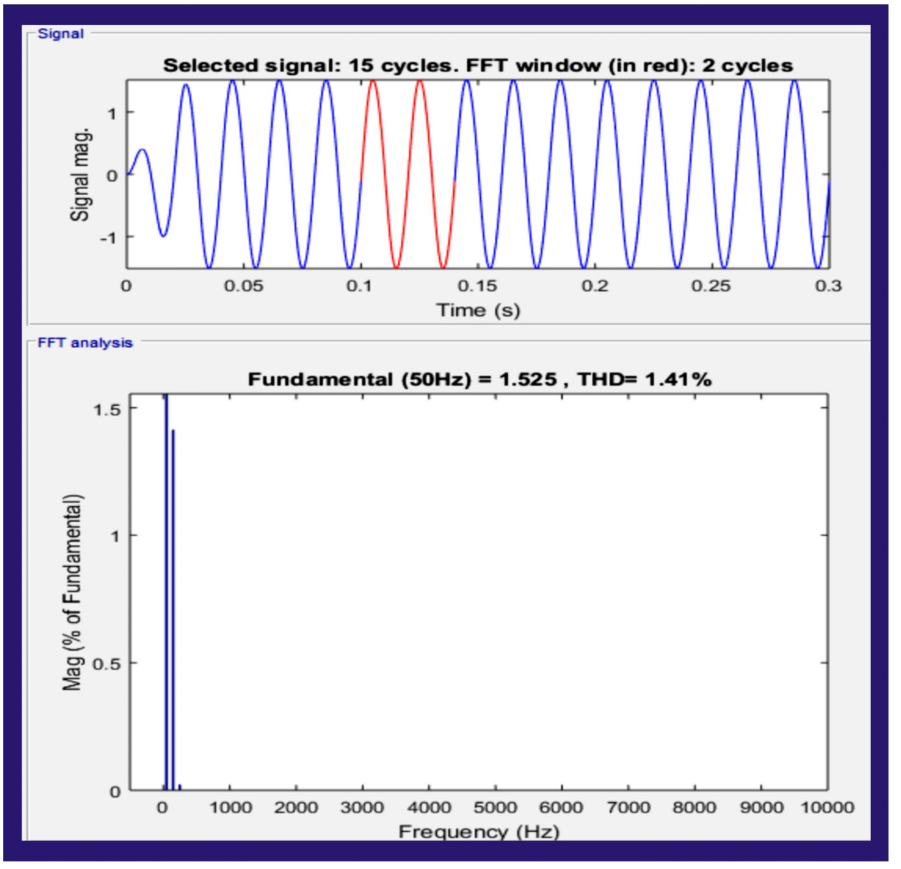

FIGURE 19 Fast Fourier transform analysis of output current

value is 1.41% with the resistive load which is well below to IEEE recommendation. As according to the IEEE standard, 5% harmonic is acceptable. So, it can be proved that the fuzzy logic-based controller with the unipolar switching technique has better results compared with the other controller. The output current and voltages have the same THD value as shown in Figure 19.

5 | EXPERIMENTAL DATA AND PERFORMANCE ANALYSIS

To authenticate the performance of this work, the hardware prototype is designed with the same parameter values as used in simulation. The designed parameters and specifications of our model are given in Table 5 . The push-pull boost converter is used to optimize the power of PV modules as the converter consists of a MOSFET transistor, while fuzzy rules operate at different irradiation. The converter is controlled through a PWM signal produced by the fuzzy-based MPPT. Different parameters of push-pull boost converter are shown in Table 5. The unipolar switching technique is used to remove the THD under linear load.

The installment of solar panels is shown in Figure 20 and the hardware prototype with pure sine wave in scope is shown in Figure 21. Furthermore, the following components are used in prototype designing as demonstrated in Figure 21.

1. PV module input
2. LCL filter
3. Push-pull boost converter
4. Inverter input (340 V DC)
5. PWM generator for inverter
6. Scope view
7. Unipolar inverter
8. AC load
9. Oscilloscope connection
10. Inverter output 220 V AC
11. Fuzzy controller for LCL filter
12. Fuzzy MPPT-Solar
13. DC link after boosting.

TABLE 5 Component values used in the hardware setup

Parameters	Values
Solar panel	250 W
Open circuit voltage (DC)	59.9 V
Short circuit current (DC)	5.49 A
Boosted voltage	340 V
MOSFET used in converter	RF540
PWM carrier frequency	32 kHz
DC link voltage	340 V
Inverted voltage	220 V
C_b	1000 μF
C_f	15 μF
L_1	3300 μH
L_2	100 μH
R_f	10 Ω

FIGURE 20 Solar panel installment

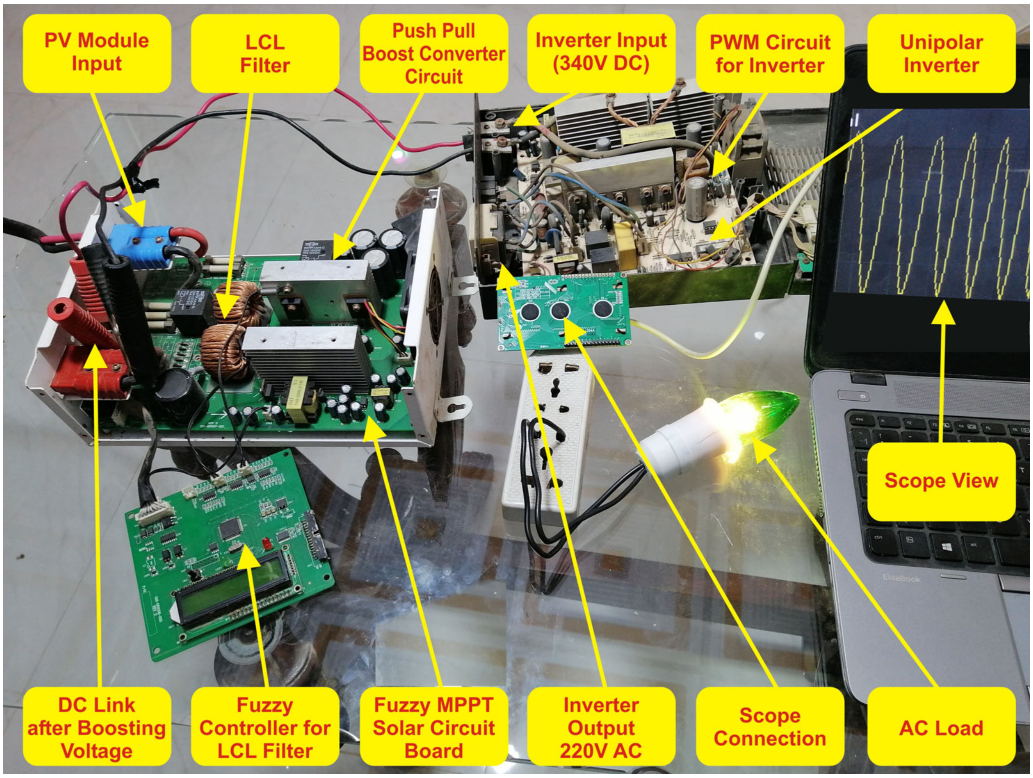

FIGURE 21 Hardware implementation

6 | CONCLUSION

The FLC controller is more robust and faster to handle nonlinearity and human knowledge. MPPT is a very important factor in the photovoltaic system and different techniques are used by researchers to attain the MPP. The fuzzy logic techniques are used in this research that provides much faster results compared with the other conventional techniques such as constant voltage method and incremental conduction method, and so on. It tracks the maximum power in 0.03 seconds as shown in simulation results. In this model, the isolated photovoltaic system is designed using a push-pull boost converter. This converter consists of the high-frequency transformer, which has much effect on the efficiency of the whole energy system as well as it provides the isolation between the load and the PV array. The DC current may be injected into AC current, if the transformer is not used than this can disturb the operation of the electric grid distribution transformer by the saturation of the magnetic core. Furthermore, the THD is reduced to only 1.41% at resistive load and the 50 Hz fundamental frequency proving that fuzzy logic close-loop inverter has the best results.

PEER REVIEW INFORMATION

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this article.

AUTHOR CONTRIBUTIONS

Muhammad Asif Rao equally contributed to the conceptualization, methodology, software, validation, visualization, and writing—original draft. Ateeq Ur Rehman equally contributed to the conceptualization, formal analysis, methodology, software, supervision, and writing—original draft, review, and editing. Saif Ur Rehman equally contributed to the software, validation, and writing—review and editing. Jehangir Arshad equally contributed to the conceptualization, project administration, supervision, and writing—review and editing. Jamshaid Hamid equally contributed to the methodology and visualization. Muhammad Tariq Sadiq equally contributed to the supervision and writing—original draft, review, and editing. Sohaib Tahir equally contributed to the software and validation.

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