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Development and validation of enhanced fuzzy logic controller and boost converter topologies for a single phase grid system

***Introduction**. Solar photovoltaic system is one of the most essential and demanding renewable energy source in the current days, due to the benefits of high efficiency, reduced cost, no pollution, and environment friendly characteristics. Here, the maximum power point tracking controller has been implemented for obtaining an extreme power from the photovoltaic array. For this purpose, there are different controller and converter strategies have been deployed in the conventional works. It includes perturb and observation, incremental conductance, fuzzy logic systems, and hill climbing, and these techniques intend to extract the high amount of power from the solar systems under different climatic conditions. Still, it limits with the issues like increased design complexity, high cost consumption, high harmonics, and increased time consumption. **The goal** of this work is to deploy an improved controlling and converter topologies to regulate the output voltage and power fed to the single phase grid systems. **The novelty** of the work aims to develop an enhanced fuzzy logic controller based maximum power point tracking mechanism with the boost DC-DC converter topology for a single phase grid tied photovoltaic systems. **Practical value**. Also, the higher order harmonics suppression and unbalanced current elimination are handled by the use of LCL filtering technique, which efficiently reduces the harmonics in the output of inverter voltage and current. Moreover, it helps to obtain the reduced total harmonics distortion value with improved accuracy and efficiency. **Results.** There are different performance indicators have been evaluated for validating the proposed enhanced fuzzy logic controller–maximum power point tracking controlling technique. Moreover, the obtained results are compared with some of the conventional controlling algorithms for proving the betterment of the proposed work.* References 30, tables 5, figures 7.

Key words: **photovoltaic systems, boost DC-DC converter, enhanced fuzzy logic controller, maximum power point tracking, LCL filtering, pulse generation, single-phase grid system**.

***Вступ**. Сонячна фотоелектрична система є одним з найбільш важливих та затребуваних відновлюваних джерел енергії в наші дні завдяки перевагам високої ефективності, низької вартості, відсутності забруднення та екологічно безпечним характеристикам. При цьому було реалізовано контролер стеження за точкою максимальної потужності для отримання екстремальної потужності від фотогальванічної батареї. З цією метою у традиційних роботах використовуються різні стратегії контролерів та перетворювачів. Це включає збурення та спостереження, інкрементну провідність, системи нечіткої логіки та сходження на пагорб, і ці методи призначені для отримання великої кількості енергії із сонячних систем у різних кліматичних умовах. Тим не менш, це обмежується такими проблемами, як підвищена складність конструкції, високі витрати, високі гармоніки та збільшення витрат часу. **Метою** цієї роботи є розвиток вдосконаленого управління та топології перетворювача для регулювання вихідної напруги та потужності, що подається до однофазних мережевих систем. **Новизна** роботи спрямована на розробку вдосконаленого механізму відстеження точки максимальної потужності на основі контролера з нечіткою логікою з топологією перетворювача постійного струму, що підвищує, для однофазних фотоелектричних систем, прив'язаних до мережі. **Практична цінність**. Крім того, придушення гармонік вищих порядків та усунення незбалансованого струму здійснюється за допомогою методу LCL-фільтрації, який ефективно зменшує гармоніку на виході інвертора напруги та струму. Крім того, це допомагає отримати зменшене значення повного гармонійного спотворення з покращеною точністю та ефективністю. **Результати**. Існують різні показники ефективності, які були оцінені для перевірки запропонованого покращеного контролера нечіткої логіки – методу керування відстеженням точки максимальної потужності. Крім того, отримані результати порівнюються з деякими звичайними алгоритмами контролю для доведення кращості запропонованої роботи.* Бібл. 30, табл. 5, рис. 7.

Ключові слова: **фотогальванічні системи, перетворювач постійного струму, що підвищує, удосконалений контролер з нечіткою логікою, відстеження точки максимальної потужності, LCL-фільтрація, генерація імпульсів, однофазні мережеві системи**.

Introduction. Solar photovoltaic (PV) systems have gained a significant attention [1, 2] in the recent days due to their benefits of easy accessibility and availability. Also, it has been widely applied in various application sectors like residential, transportation, and construction. Typically, the PV systems [3] can produce the required amount of energy from solar for the grid connected systems with the help of appropriate methodologies and equipment. The important features of the solar PV systems are cost efficiency, pollution free, maintenance free, and high availability rate [4]. The major challenges that are associated with the grid integrated PV systems [5] can be categorized under the components of PV panel, power converters, and grid system. In which, the processes of optimization, voltage/current maintenance, and panel monitoring are need to be highly concentrated on the PV panel. Then, the efficiency, high reliability, temperature measurement, communication, monitoring and safety measures are need to be satisfied by the power converter topologies. Moreover, the power quality improvement, voltage level maintenance, and fault ride through capability are the dependable factors of the converter and controller topologies, and these factors supports to obtain an improved system performance [6]. In the solar PV systems, the PV array can be categorized with respect to the solar irradiation and temperature measures. So, it required an operating point for extracting the maximum power from the PV array that is represented as an MPPT controller [7].

Then, it helps the PV arrays to obtain the maximum efficiency under varying climatic conditions. Generally, there are different types of maximum power point tracking (MPPT) controlling techniques have been utilized in the traditional works, which includes incremental conductance (IC) [8], fuzzy controller [9], perturb and observe (P&O) [10], and temperature gradient [11]. Also, various power converter design topologies have been utilized in the existing works [12] like buck converter, bi-directional converter, SEPIC converter, and Luo converter. But, these techniques limits with the issues like increased circuit design complexity, high cost consumption, reduced speed, and requires an accurate model. Moreover, harmonics elimination and current balancing are also plays an important role in a single phase grid integrated PV systems [13, 14]. The filtering techniques can be used to suppress the level of harmonics for improving both efficiency and system stability [15, 16]. Thus, the proposed work focused on the development of an advanced controlling mechanism for a single phase tied PV systems. The major objectives behind the proposed work are as follows:

- to obtain the maximum power extraction from the PV panels, the functionalities of an enhanced fuzzy logic controller (EFLC) is incorporated with the MPPT controlling technique;
- to improve the operating efficiency of the entire grid system, the boost converter topology is utilized;
- to reduce the unbalanced current, and harmonics distortion, a higher order LCL filtering technique is employed.

Related works. This sector reviews some of the existing controlling techniques and converter topologies related to the solar PV power generation and extraction. Also, the working operations of the converter and controller topologies have been discussed with its own merits and demerits.

Podder, et al. [17] conducted an extensive review about the MPPT methods used for generating the power from solar PV systems. The different methods analyzed in this work were P&O, IC, and hill climbing (HC). Also, various types of DC-DC converter topologies such as buck, boost, bidirectional, CUK, flyback, SEPIC and Zeta were compared based on the measures of computation performance, input current, and output voltage. From this study, it was analyzed that the P&O was the most suitable MPPT technique for solar PV systems due to the benefits of simplicity and reduced cost consumption. Kumar, et al. [18] deployed a neural network based controlling technique for improving the performance of grid based solar PV systems. The key factor of this work was to obtain the maximum power extraction with increased utilization factor and efficiency by using the HC-MPPT mechanism. Still, this work failed to reduce the harmonics distortion for obtaining the better performance rate. Basha and Rani [2] analyzed the performance 5 different MPPT techniques such as HC-FLC (fuzzy logic controller), ANFIS (adaptive neuro-fuzzy inference system), PSO (particle swarm optimization), ACS (adaptive cuckoo search), and P&O for selecting the suitable technique to get an extreme power extraction from PV systems. Here, it was stated that the operating point estimation plays an essential role during MPP extraction, which could be more helpful to reduce both the operating and installation costs.

Venkatraman and John [19] intended to increase the performance of MPPT with the use of buck converter topology for PV charging system. Here, the P&O algorithm has been utilized to reduce the settling time, increase the bandwidth, and improve the tracking performance. From the paper, it was perceived that the P&O scheme offered the better results with minimum possible updation. Keyrouz [20] aimed to gain the maximum power obtainment from the solar PV systems under varying temperature and irradiation values. For this purpose, a machine learning technique, named as, Bayesian function has been utilized to obtain global MPP in a specified time. Moreover, the PID (proportional integral derivative) controller was used to reduce the overshoot and rise time with high tracking efficiency. Priyadharshi, et al. [21] employed a hybrid Gravitational Search Algorithm (GSA) – PSO technique for improving the tracking performance of MPP. In this design, the CUK-SEPIC converter was adopted to reduce the ripple content and to obtain the optimum PV value. During optimization, the processes of fitness evaluation, global best solution estimation, and position updation have been performed. The major benefit of this work was, it has the ability to work under low sun isolation level with reduced cost consumption.

Basha and Rani [22] suggested high step-up boost converters for increasing the tracking efficiency of MPPT controlling technique. In this work, there were different MPPT techniques have been surveyed that includes variable step size P&O, fractional open circuit voltage (FOCV) and modified IC (MIC). Also, the working descriptions of these mechanisms have been described with its pros and cons. Hassan, et al. [23] recommended an FLC controller and push-pull converter for optimizing the output power of PV systems with increased gain value. The work focused on tracking the power from PV panels without any oscillations and noise with the help of FLC MPPT mechanism. From this work, the importance and benefits of using FLC mechanism in solar PV systems have been studied. Li, et al. [24] implemented the beta parameter based FLC mechanism for improving the performance of MPP in solar PV systems. Here, the number of fuzzy rules has been reduced for simplifying the process of membership function generation. Rezk, et al. [25] employed an adaptive FLC (AFLC) based controller topology for obtaining an improved efficiency of PV applications. This methodology was mainly deployed to attain an accurate and optimum tracking performance with reduced power fluctuations. The key advantages of this controller were faster convergence, high accuracy, and simplicity. Karafil, et al. [26] designed a high frequency resonant converter design with the pulse density modulation – MPPT mechanism for a single phase grid based PV systems. In this controlling algorithm, certain controlling pulses have been eliminated with respect to the command sequences without any deviation in the frequency value.

Sun, et al. [27] utilized an artificial neural network (ANN) based controlling strategy for an efficient power tracking from the PV array. The main scope of this work was to ensure the factors of reliability, safety, improved performance and controllability of a grid connected PV systems. Here, some of the major requirements that could be used for controlling the solar PV system have been discussed, which includes:

1. Exact tracking of MPP under varying irradiance and temperature measures.
2. Accurate locating of MPP.
3. Maintain the same MPP value under different climatic conditions.

Bhattacharya, et al. [28] applied an advanced controlling mechanism based on ANN algorithm for a grid connected PV systems. In this work, the conventional PI (proportional integral) controlling mechanism has been replaced with the functionality of ANN algorithm. Then, it offered an improved system performance with improved dynamic response and reduced settling time. Rajput, et al. [29] suggested a second order filtering technique for increasing the power extraction of single phase grid associated PV systems. Here, a robust controlling mechanism with the boost converter topology has been implemented and validated under various power quality enhancement features. Gomes, et al. [30] implemented an LCL filtering technique for eliminating the harmonic distortions in the grid connected voltage source converters. Here, a detailed analysis about harmonics elimination, and clear illustration about the damping techniques were discussed.

From this study, the impact of different MPPT controlling mechanisms, converter designs, and filtering approaches were analyzed with its working definitions. Then, it will be more helpful for selecting the suitable approaches that are used for improving the overall performance of solar PV systems.

EFLC-MPPT based controlling strategy. In this segment, a clear description about the proposed EFLC based MPPT mechanism is presented for a single phase grid systems. The purpose of this paper is to extract the maximum amount of power from the solar PV systems under varying climatic conditions by implementing an advanced converter and controlling techniques. Here, the boost DC-DC converter has been utilized to increase the efficacy of overall system performance. In addition to that, the reactive power support and harmonics elimination are also concentrated to provide the reliable output for the single phase grid systems. For this purpose, the LCL filtering technique is employed to decrease the harmonics and unbalanced current in the grid systems. The block and schematic representations of the proposed EFLC-MPPT based controller design are presented in Fig. 1, 2 respectively, which comprises the following stages:

- power extraction using EFLC-MPPT;
- boost DC-DC converter design;
- LCL filtering.

The purpose of this work is to obtain the maximum amount of energy from the solar panels by implementing an advanced controlling and converter topologies. Normally, the performance of entire power generation system is highly depends on the controlling signals generated by the controller. Here, the switching pulses generated by the proposed EFLC-MPPT controlling mechanism are fed to boost converter for operating the switching components. When compared to the other controlling models reviewed in the literature, the proposed EFLC-MPPT integrated with boost topology could efficiently produces the regulated output voltage fed to single phase grid systems. Also, it suppresses the harmonic contents by regulating the output of PV panels with reduced loss of power.

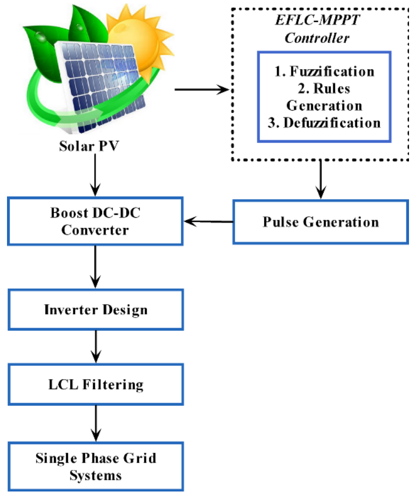

Fig. 1. Block representation of EFLC-MPPT based controller design

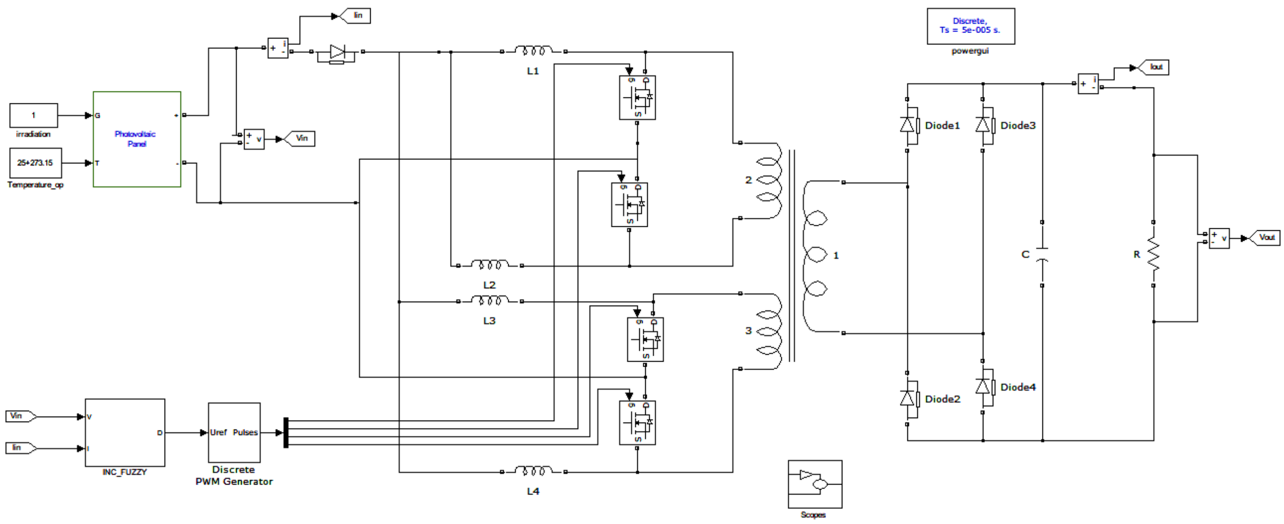

Fig. 2. Schematic representation of the EFLC-MPPT controller design

EFLC-MPPT based power extraction. At first, the maximum power tracking from the PV panel is performed by using the controlling technique. The essential part of the PV system is PV array, which is used to generate the required power from the solar. The MPPT controller has been used to increase the amount of power generation from PV array. Conventionally, there are different types of MPPT techniques are available for power extraction, in which the FLC is one of the extensively used controlling mechanism due to the non-linear structure of the converter. Also, it could act as a controller that helps to obtain the requirements and specifications of the plants. In this work, an EFLC based MPPT mechanism is deployed for extracting the maximum power from the solar PV systems with increased static and dynamic performance. The typical illustration of the EFLC system is depicted in Fig. 3, which comprises the following stages: fuzzification, inference rule generation, and defuzzification. During fuzzification, the set of inputs like temperature and irradiation are incorporated with the stored membership function, which can be assigned to each fuzzy input. Then, the rule evaluation process is performed with the help of linguistic rules, which is used to determine the control action with respect to the set of input values. From the rule evaluation, the fuzzy output can be obtained for each subsequent action. At last, the expected output variable is computed based on the isolation of the output fuzzy sets during defuzzification.

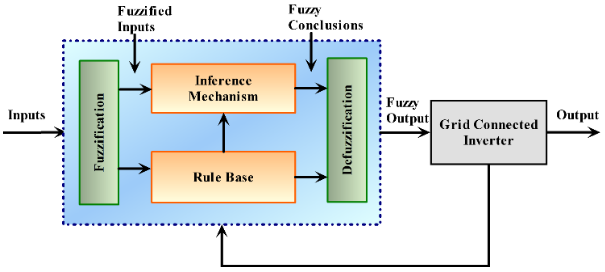

Fig. 3. Working strategy of fuzzy controller

Let consider the inputs as error (E_r) and change of error (CE_r), which are represented as follows:

$$E_r(x)=\frac{P_{PV}(x)-P_{PV}(x-1)}{V_{PV}(x)-P_{PV}(x-1)}; \qquad (1)$$

$$CE_r(x)=E_r(x)-E_r(x-1); \qquad (2)$$

where $P_{PV}(x)$ is the PV power; $V_{PV}(x)$ is the PV voltage; $P_{PV}(x–1)$ and $V_{PV}(x–1)$ are the previous power and voltage respectively.

Then, the rule generation process can be carried out based on the Mamdani model. Here, the 5 set of rules such Very Low (VL), Low (L), Very High (VH), High (H), and Medium (M) have been generated with respect to the error and change of error values as shown in Table 1.

Table 1

Fuzzy rules generation

CE_r \ E_r	VL	L	M	H	VH
VL	VH	VH	H	VL	VL
L	H	H	H	VL	L
M	H	H	N	L	L
H	H	H	L	L	VL
VH	H	H	L	L	VL

After inference rules generation, the defuzzification process can be applied to get the output that is denoted as the duty cycle D_c, which is represented as follows:

$$D_c=\frac{\sum_{i=1}^{n}\mu(D_{ci})-D_{ci}}{\sum_{i=1}^{n}\mu(D_{ci})}; \qquad (3)$$

Moreover, the key benefits of using ELFC-MPPT controller are as follows:

- it has the ability to handle an inaccurate input;
- it does not require any exact mathematical model;
- it has a non-linearity structure;
- it helps to obtain the maximum power output under different climatic conditions;
- it offers reduced complexity in design;
- it increased robustness.

The P-V and I-V characteristics of the proposed EFLC-MPPT controlling mechanism are depicted in Fig. 4,*a*,*b*. These characteristics can be used to validate the overall efficacy of the MPPT controlling technique. Based on the I-V and P-V characteristics analysis, it is evident that the EFLC-MPPT provides the better current and power values with respect to different voltage levels.

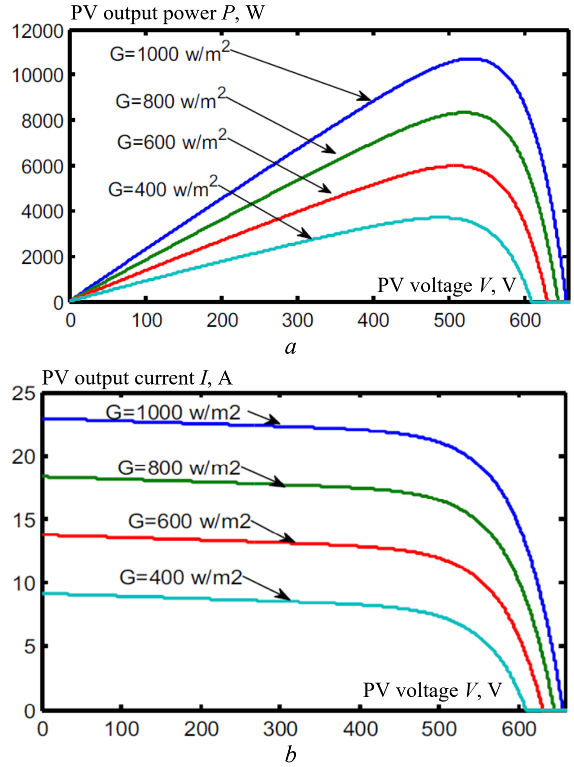

Fig. 4. P-V (*a*) and I-V (*b*) characteristics

Boost DC-DC converter design. Here, the boost DC-DC converter is placed between the PV panel and grid system for changing the output voltage with respect to the maximum power point. The corresponding circuit model of boost converter is represented in Fig. 5, which contains the components of input source voltage V_{in}, inductor L, diode D, switch Q, capacitor C, and output load. Based on the requirement of output, the switch can be either opened or closed, in which the output voltage is always greater than the value of input voltage source. The main factor of using this converter design is to increase the voltage level without use of transformer. Also, it offers an increased efficiency with the inclusion of single switching component.

The transfer function of the boost converter can be illustrated as follows:

$$V_o = D_c \cdot V_{PV}, \qquad (4)$$

where V_o is the output voltage; D_c is the duty cycle of the control; V_{PV} is the output voltage of PV array.

Based on the Kirchhoff's voltage and current law, the relationship between the input and output of boost converter is illustrated as follows:

$$L\cdot\frac{dI_o}{dt}=V_{PV}-V_L; \qquad (5)$$

$$C\cdot\frac{dV_{PV}}{dt}=I_o-V_L/R; \qquad (6)$$

where R is the resistance; L is an inductor; I_o is the output DC-DC current.

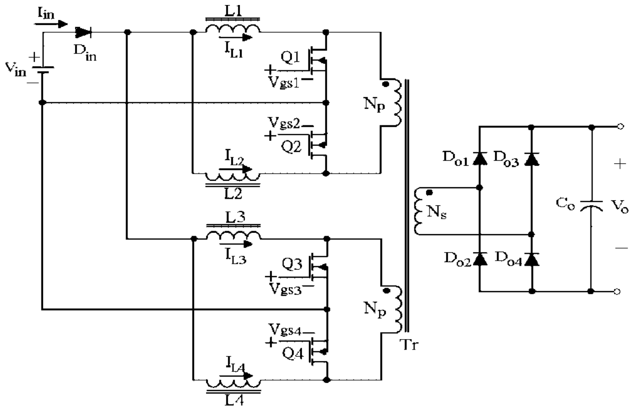

Fig. 5. Schematic representation of the circuit design

LCL filtering. The output of boost converter is given to the filtering unit for removing the harmonics and unbalanced current. Here, an LCL filtering technique is mainly deployed to protect the gird system from switching harmonics, and to obtain improved dynamic performance. Moreover, it offers better decoupling between the grid impedance and filtering with good ripple attenuation. The LCL filter can be composed based on the series connected $L_1 + R_1$, $L_2 + R_2$, and $C + R_c$ components, which helps to eliminate the injected harmonics on the grid. The mathematical model of LCL filtering technique can be illustrated as follows:

$$\begin{cases} L_1 \cdot \dfrac{\mathrm{d}i_1}{\mathrm{d}t} + R_1 \cdot i_1 = x_i - x_c - R_c \cdot i_c; \\ L_2 \cdot \dfrac{\mathrm{d}i_g}{\mathrm{d}t} + R_2 \cdot i_2 = x_c - x_g - R_c \cdot i_c; \\ C \cdot \dfrac{\mathrm{d}x_c}{\mathrm{d}t} = i_c; \\ i_1 = i_g + i_c. \end{cases} \quad (7)$$

Then, the resonant frequency is estimated as follows:

$$R_{fr} = \frac{1}{2\pi} \cdot \sqrt{\frac{L_1 + L_2}{L_1 \cdot L_2 \cdot C}}, \quad (8)$$

where R_{fr} is the resonant frequency of filter; L_1, L_2 are the inductors; R_1, R_2 are the resistors; C is the capacitor.

The key merits of using LCL filtering technique in this design are efficient total harmonics distortion (THD) elimination, high attenuation ability, and better system stability.

Results and discussion. The performance evaluation of the proposed EFCL-MPPT controlling mechanism is done in this sector with respect to different performance indicators. This controlling system has been designed by using the MATLAB/Simulink software, where the PV array under irradiance of 1000 W/m^2 and temperature of 25 °C.

Simulation results. Figure 6 shows the output power (*a*), irradiance (*b*) and temperature (*c*) analysis with respect to varying time. In this simulation, the system is tested under different irradiance levels of 800 W/m^2, 400 W/m^2, and 1000 W/m^2. This results shows that the proposed EFLC-MPPT technique efficiently tracks the maximum power of 200 W, 150 W, and 250 W respectively with the time of 5 ms.

Figure 7 shows the inverter output voltage (*a*) and current (*b*) after eliminating the harmonics by using the LCL filtering technique. To validate the output of inverter voltage and current, the THD is estimated for the proposed controlling mechanism.

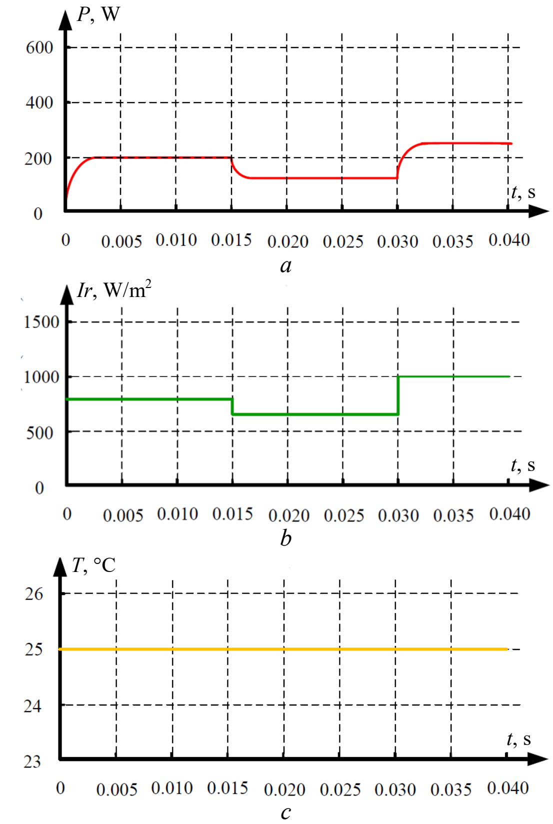

Fig. 6. Output power (*a*); irradiance (*b*); temperature (*c*)

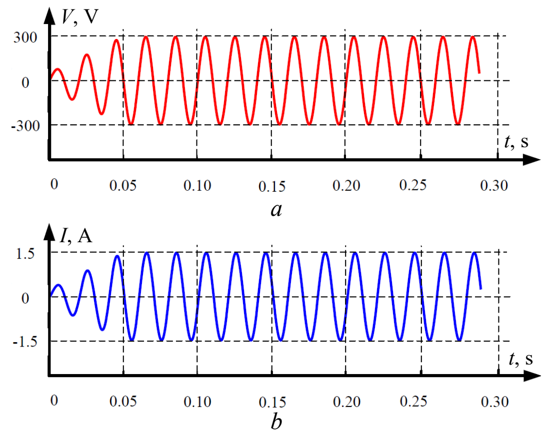

Fig. 7. Inverter output voltage (*a*) and current (*b*)

Comparative analysis. Generally, the efficiency of the filtering technique can be determined based on the analysis of THD. Table 2 depicts the THD analysis of existing and proposed techniques with respect to varying irradiation (W/m^2). In this work, an LCL filtering circuit is implemented in this design for suppressing the high order harmonics and unbalanced current in an efficient manner. Based on the result outcomes, it is evident that the proposed mechanism EFLC-MPPT with LCL filtering could efficiently reduce the THD value, when compared to the existing filtering technique.

Table 2

THD analysis

Irradiation I_r, W/m^2	400	800	1000
Existing THD, %	1.72	1.95	2.14
Proposed THD, %	1.68	1.93	1.95

Table 3 compares the existing FLC, P&O and proposed EFLC-MPPT controlling techniques with respect to the measures of input voltage V_{in}, input current I_{in}, input power P_{in}, output voltage V_o, output current I_o and output power P_o. Based on the comparative analysis, it is proved that the EFLC-MPPT could offer an improved results compared than the conventional techniques.

Table 3
Comparative analysis between existing and proposed controlling techniques

Topologies	V_{in}, V	I_{in}, A	P_{in}, W	V_o, V	I_o, A	P_o, W
Conventional FLC	12.08	1.03	12.44	24.6	0.485	11.93
Conventional P&O	8.5	2.5	21.25	31.30	0.622	19.3
EFLC-MPPT	12.08	2.932	59.94	35.42	2.785	166.9

Moreover, the proposed EFLC-MPPT technique could efficiently extract the maximum power from the solar PV systems by the use of boost converter and LCL filtering components. Also, it helps to obtain an improved performance rate of the single phase grid systems.

Table 4 shows the comparative analysis between the existing and proposed MPPT controlling techniques under varying irradiance measures such as 400 W/m^2, 800 W/m^2 and 1000 W/m^2. The measures that have been compared in this analysis are PV voltage V_{PV}, duty cycle D_c, output voltage V_o and output power P_o. When compared to the existing controlling techniques, the proposed EFLC-MPPT technique provides improved results for the varying irradiance measures.

Table 4
Comparative analysis between the existing and proposed MPPT mechanisms

	under 800 w/m^2 (0 to 0.6 s)				under 400 w/m^2 (0.6 to 1.2 s)					under 1000 w/m^2 (1.2 to 1.8 s)				
MPPT method*	V_{PV}, V	D_c	V_o, V	P_o, W	V_{PV}, V	D_c	V_o, V	P_o, W	V_{PV}, V	V_{PV}, V	D_c	V_o, V	P_o, W	V_{PV}, V
VSS-P&O	34.0	0.604	86.0	148.44	17.0	0.711	59.0	77.0	17.0	38	0.59	94	196.31	38
MIC	34.3	0.601	86.1	150.7	17.5	0.7	59.6	77.8	17.5	39.2	0.58	95.31	197.48	39.2
FOCV	33.8	0.62	89	155	17.0	0.715	59.8	78.0	17.0	39.28	0.59	96	197.5	39.28
FSS-RBFA	33.0	0.627	87.0	155.76	17.4	0.719	62	79.53	17.4	40.1	0.586	96.8	198.78	40.1
VSS-RBFA	34.2	0.609	87.5	156.5	18.5	0.72	66.4	79.6	18.5	39.8	0.6	100.5	200.2	39.8
AFLC	34.8	0.614	90.32	158.2	24.0	0.64	68.0	80.0	24.0	45.3	0.56	105	201.8	45.3
PSO	34.71	0.622	92.0	158.5	24.8	0.66	73.7	82.0	24.8	47.07	0.64	132	204.40	47.07
CS	37.27	0.59	93.17	161.73	25.76	0.65	73.89	82.2	25.76	47.54	0.65	138	205.18	47.54
Proposed EFLC-MPPT	39.28	0.55	94.23	162.35	26.2	0.59	74.2	83.5	26.2	48.20	0.62	139	206.25	48.20

*VSS-P&O – variable step size- perturb and observe; MIC – modified incremental conductance; FOCV – fractional open circuit voltage; FSS-RBFA – fixed step size-radial basis function algorithm; VSS-RBFA – variable step size-radial basis function algorithm; AFLC – adaptive fuzzy logic controller; PSO – particle swarm optimization; CS – cuckoo search; EFLC-MPPT – enhanced fuzzy logic controller-maximum power point tracking.

Table 5 depicts the tracking time of the existing P&O and IC, and proposed MPPT controlling mechanisms. Typically, the tracking time is one of the important measures to validate the tracking efficiency of the controlling technique. Moreover, it is defined as how much amount of time that the controller could take for tracking the maximum power point from the PV panel. From the results, it is evident that the proposed EFLC-MPPT provides the reduced tracking time of 5 ms, when compared to the other controlling techniques.

Table 5
Tracking time of existing and proposed MPPT techniques

MPPT mechanisms	Tracking time, s
P&O	0.3
IC	0.25
Proposed EFLC-MPPT	0.005

Conclusions. A new enhanced fuzzy logic controller integrated with boost converter topology design is implemented in this paper for obtaining an extreme power extraction from the solar panels. Here, the boost DC-DC converter is mainly used to increase the voltage level without use of transformer. Also, the proposed controlling topology intends to extract the power under varying climatic conditions with increased accuracy. In addition to that, an LCL filtering circuit is employed in the proposed design for suppressing the harmonics and unbalanced current in the inverter output. The major benefits of the proposed design are, it has the ability to handle an inaccurate input and does not require any exact mathematical model for controlling. During performance evaluation, the controlling technique could be tested under different irradiance values of 400 W/m^2, 800 W/m^2, and 1000 W/m^2. Moreover, some of the traditional controlling techniques are compared with the proposed controlling mechanism based on the measures of harmonic distortions, tracing time, PV output power, voltage, and current. Based on the comparative analysis, it is studied that the proposed controlling technique offers an improved performance results compared than the conventional techniques.

In future, this work can be extended by implementing an optimization based controlling mechanism for a single-phase grid system.

Conflict of interest. The authors declare that they have no conflicts of interest.

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