IEEE Access
Multidisciplinary | Rapid Review | Open Access Journal

Received October 19, 2020, accepted November 8, 2020, date of publication November 16, 2020, date of current version November 27, 2020.

Digital Object Identifier 10.1109/ACCESS.2020.3038313

Power Enhancement With Grid Stabilization of Renewable Energy-Based Generation System Using UPQC-FLC-EVA Technique

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ABSTRACT The proposed work focuses on the power enhancement of grid-connected solar photovoltaic and wind energy (PV-WE) system integrated with an energy storage system (ESS) and electric vehicles (EVs). The research works available in the literature emphasize only on PV, PV-ESS, WE, and WE-ESS. The enhancement techniques such as Unified Power Flow Controller (UPFC), Generalized UPFC (GUPFC), and Static Var Compensator (SVC) and Artificial Intelligence (AI)-based techniques including Fuzzy Logic Controller (FLC)-UPFC, and Unified Power Quality Conditioner (UPQC)-FLC have been perceived in the existing literature for power enhancement. Further, the EVs are emerging as an integral domain of the power grid but because of the uncertainties and limitations involved in renewable energy sources (RESs) and ESS, the EVs preference towards the RES is shifted away. Therefore, it is required to focus on improving the power quality of the PV-WE-ESS-EV system connected with the grid, which is yet to be explored and validated with the available technique for enhancing power quality. Furthermore, in the case of the bidirectional power flow from vehicle-to-grid (V2G) and grid-to-vehicle (G2V), optimal controlling is crucial for which an electric vehicle aggregator (EVA) is designed. The designed EVA is proposed for the PV-WE-ESS-EV system so as to obtain the benefits such as uninterruptible power supply, effective the load demand satisfaction, and efficient utilization of the electrical power. The power flow from source to load and from one source to another source is controlled with the support of FLC. The FLC decides the economic utilization of power during peak load and off-peak load. The reduced power quality at the load side is observed as a result of varying loads in the random fashion and this issue is sorted out by using UPQC in this proposed study. From the results, it can be observed that the maximum power is achieved in the case of PV and WE systems with the help of the FLC-based maximum power point tracking (MPPT) technique. Furthermore, the artificial neural network (ANN)-based technique is utilized for the development of the MPPT algorithm which in turn is employed for the validation of the proposed technique. The outputs of both the techniques are compared to select the best-performing technique. A key observation from the results and analysis indicates that the power output from FLC-based MPPT is better than that of ANN-based MPPT. Thus, the proper and economical utilization of power is achieved with the help of FLC and UPQC. It can be inferred that the EVs can play a vital role in imparting the flexibility in terms of power consumption and grid stabilization during peak load and off-peak load durations provided that the proper control techniques and grid integration are well-established.

INDEX TERMS PV system, Energy storage system (ESS), electric vehicles (EVs), UPQC, grid stability, fuzzy logic control (flc), electric vehicle aggregator (EVA), MPPT, power improvement.

The associate editor coordinating the review of this manuscript and approving it for publication was N. Prabaharan.

I. INTRODUCTION

The conventional energy resources are being substituted by RESs, such as solar, wind, tidal and many others. Also. the utilization of RESs is increasing tremendously because these are clean, easy to access, and abundant in nature. Moreover, a favourable scenario such as the reduction in global warming and less emission of carbon dioxide has been observed when RESs are implemented. Therefore, RESs prevails as better alternatives to conventional resources. The increasing load demand can also be fulfilled by introducing RESs in existing power grid [1]. In spite of having numerous advantages, the solar and wind energy resources are highly sensitive to the weather and geographical location, which are the prime drawbacks of using RESs. These drawbacks affect the grid stability to the greater extent which can be potentially minimized by integrating the RESs with ESS.

The various problems associated with RESs and the process to overcome those problems are detailed in the referred study [2]–[4]. The uncertainties involved in PV system cause Total Harmonic Distortion (THD) in the grid. As a result of which the load voltage and current are distorted. Therefore, the Flexible AC Transmission System (FACTS) devices have been utilized to overcome the THD and voltage stabilization issues. The FACTS devices, including UPFC, UPFC-FLC, GUPFC, UPQC, and SVC are the commonly used devices to improve power quality. The implementation of FACTs devices fixes the voltage stability issue and simultaneously, improves the grid power quality [5]–[7]. The enhancement in grid stability and reduction in THD have been achieved by implementing the Static Compensator (STATCOM) accompanying with ESS [5]. Similarly, wind power generation system experiences unstable voltage and THD. Therefore, STATCOM has also been implemented with the grid-connected WE system [6]. The three FACTS devices, including Dynamic Voltage Restoration (DVR), Distribution STATCOM (DSTATCOM), and UPQC have been implemented for power quality improvement and voltage stabilization [7]. Moreover, the implementation of UPQC in the grid-connected PV system has been discussed for power quality enhancement [8]. The WE integrated grid system has been considered for power quality improvement using UPQC [9]. The power quality of the grid connected RESs can be improved using various MPPT algorithms based on FLC and ANN. Further, the uncertainties involved in RESs can be avoided using FLC-based MPPT algorithms. The FLC-based MPPT have been implemented for avoiding the weather-induced uncertainties related to the solar PV output power [10], [11]. The authors concluded that the proposed method has overcome the conventional methods for power quality enhancement.

The converters are used along with the RESs to convert the power and make it suitable for connecting to the grid. The configuration layout of hybrid microgrid, including PV and WE has been provided in the referred study [12] in which the RESs are connected with a bidirectional converter. Various factors including average wind speed, irradiation, and temperature are needed to be considered while modelling the PV and WE systems as RESs are sensitive to weather and location. The scenario of RESs for various countries such as India, China, Iceland, Sweden, and the USA differ widely [2], [3]. To add upon it in WE system, the output power capacity is different on onshore and offshore [13]. Therefore, depending upon the various factors affecting the PV and WE systems, flexible mathematical model and optimization techniques are required to model the seasonable WE and PV systems. The non-linear characteristics of PV are challenging to design. Therefore, various optimization techniques like particle swarm optimization are used to estimate the parameters associated with the PV system and to improve the power output of PV and WE systems [14]. These techniques would ultimately help in configuring the RESs modelling. The RESs configurations available in literature are illustrated in Table 1.

TABLE 1. Most frequently used RESs configurations in the existing literature for the analysis of grid stabilization and power improvement.

Configuration	Reference
PV	[15]
PV-ESS	[16]
WE	[17]
WE-ESS	[18]
PV-WE	[19], [20]
PV-WE-ESS	[20]
PV-ESS-grid	[21], [22]
WE-ESS-grid	[23]
PV-WE-ESS-grid	[24], [25]
PV-ESS-EV-grid	[26]
PV-WE-ESS-EV-grid	Proposed work

Among the power electronic-based FACTS techniques, the UPQC has better performance when compared to other techniques, essentially STATCOM, DVR, and SVC. The UPQC fulfills most of the desired qualities, including voltage improvement, harmonic mitigation, current improvement, and overall power quality improvement of the system [8], [27]. Therefore, UPQC is utilized in this study to improve the power output quality of the PV-WE-ESS-EV system integrated with EVs and ESS. A dynamic battery controller is designed to effectively control the ESS system. On the other hand, EVA is implemented for controlling the EVs system, which manages the power transfer between the PV-WE-ESS system and EVs. The UPQC connected with the PV-WE-ESS-EV system functions in two ways which are as follows [28].

- The series part of UPQC (active converter) helps to reduce the harmonic mitigation and voltage disturbances.
- The shunt part of UPQC (active converter) helps to reduce the current distortion and improve the dc-link voltage regulation.

The implementation of UPQC for a solar PV system and its investigation under an unbalanced loading condition has also been carried out [29]. The authors concluded that the implemented UPQC was able to improve both the power quality and harmonic mitigation. The controlling of the PV-UPQC system has been done using a proportional-integral (PI) controller, FLC, or neural network (NN)-based algorithm. The PI controller has been used to control the working of PV-UPQC [30] and FLC technique has been used for improving the power quality in the PV-UPQC system integrated with a battery storage system (BSS) [27]. The authors have provided a comparative analysis between the PI and FLC techniques and concluded that the FLC technique gives better results for the PV-UPQC-BSS system relative to the other technique based on PI. The implementation of the NN approach in PV-UPQC for power quality improvement has been mentioned [31], [32]. This technique requires proper learning and validation before implementing it to the electrical system. It consumes more time to evaluate the output response of the system but it gives accurate and appropriate responses. EVs also support to improve the power quality when used in parallel with grid connected ESS integrated RESs. The role of EVs, charging schemes, and benefits are discussed in [33]–[35]. The EVs are mainly for transportation purpose and thus, the availability of EVs is uncertain. For this issue, the EVA is used to manage the availability and to allot the charging-discharging schedule of EVs connected to the grid [36], [37]. The EVA enables the grid system to control the charging and discharging operation and acts as a mediator controller between the grid and the vehicles. This helps the grid system to improve the quality of power, reduce the THD, load balancing, and to improve the voltage profile under different load unbalancing conditions. Several controlling techniques and optimization techniques of the EV system connected with the grid have been discussed [38], [39].

The block diagram of the proposed system is illustrated in Fig. 1. A three-phase, three-wire grid is integrated with the PV, WE, ESS, and EVs through a phase inverter. The line-to-line voltage of the system and frequency is 254.4 V and 50 Hz, respectively. The voltage disturbance is observed due to non-linear loading, voltage swell, and voltage sag. To overcome this issue, a UPQC is designed and connected to the grid for voltage regulation. Two WE systems having 30 kW power output each are connected which totals the generated power through WE is 60 kW. The ESS system contains a battery bank connected to the grid having 36 series connected 12V, 100 Ah batteries. The capacity of the ESS system is 40 kWh and is connected to the grid through a bidirectional converter. The capacity of the PV system is 100 kW. The PV and WE systems are connected to the grid through boost converters. In this work, EVs are also considered each having a capacity of 29 kW. The FLC and ANN-based MPPT algorithms are designed for both PV and WE systems. The problem statement, contributions and objectives of this research work are highlighted in the next section.

The paper is organized as follows. The problem formulation along with contribution and objectives is discussed in Section II. Section III presents the methodologies involved in this research work that include the modelling of PV and WE systems and the connection with EVs and ESS systems, modelling of UPQC, and modelling of FLC and ANN-based MPPT algorithms. The control of charging-discharging of ESS and EVs is achieved using the FLC technique which controls the whole system. The control diagram and rules are explained in Section IV. Section V discusses the results obtained from FLC and ANN control of the PV-WE-ESS-EV system and performance of the UPQC-FLC-EVA technique in power enhancement and THD reduction. Section VI provides a comparative analysis of both FLC and ANN based-techniques for power improvement and THD reduction. Finally the work is concluded along with the future scope of this work in Section VII.

II. PROBLEM FORMULATION

From the literature survey, it can be inferred that the power quality improvement of PV, WE, PV-ESS, and WE-ESS systems have been carried out using various techniques such as UPQC, UPQC-PI, UPQC-FLC, and UPQC-NN. Nowadays, EVs are also becoming a part of the PV-ESS system and need to be considered in power quality improvement issues along with the PV-ESS system. The function of EVA is to manage the power flow between EV, ESS, and PV systems. Thus it can also act as an essential component for improving the quality of power. Therefore, the main contribution of this work focuses on the power quality improvement of the PV-WE-ESS-EV system. The roles of EVs and UPQC on power enhancement and grid stabilization are highlighted. It is observed that during the peak load demand in the grid, the excess power demand is managed from the ESS and EVs. The condition of the worst case is also considered that is when the availability of power from RESs is less and the grid power does not suffice to satisfy the load demand. During such a situation, the EVA manages the power demand of the grid-connected load by arranging EVs. The EVA controller operates and manages power from EVs to grid or grid to EVs with the help of a load forecasting system, power generation forecasting system of RESs, and nearby charging stations. The use of UPQC along with EVs to the grid system provides improved power and voltage stabilization which is shown in detail in this work. It means that the main objective of implementing EVA is to manage the utilization of EVs as a temporary battery storage system which is transportable and thus, the stored energy can be also utilized for transportation purpose when it is not required to be used as ESS. The FLC technique is used in this work to control the proposed technique and the results obtained are compared with the ANN approach. The FLC is refreshed in every 0.01 second for the grid stabilization and power improvement.

The main objectives of the proposed technique and grid system integrated with RESs include the following:

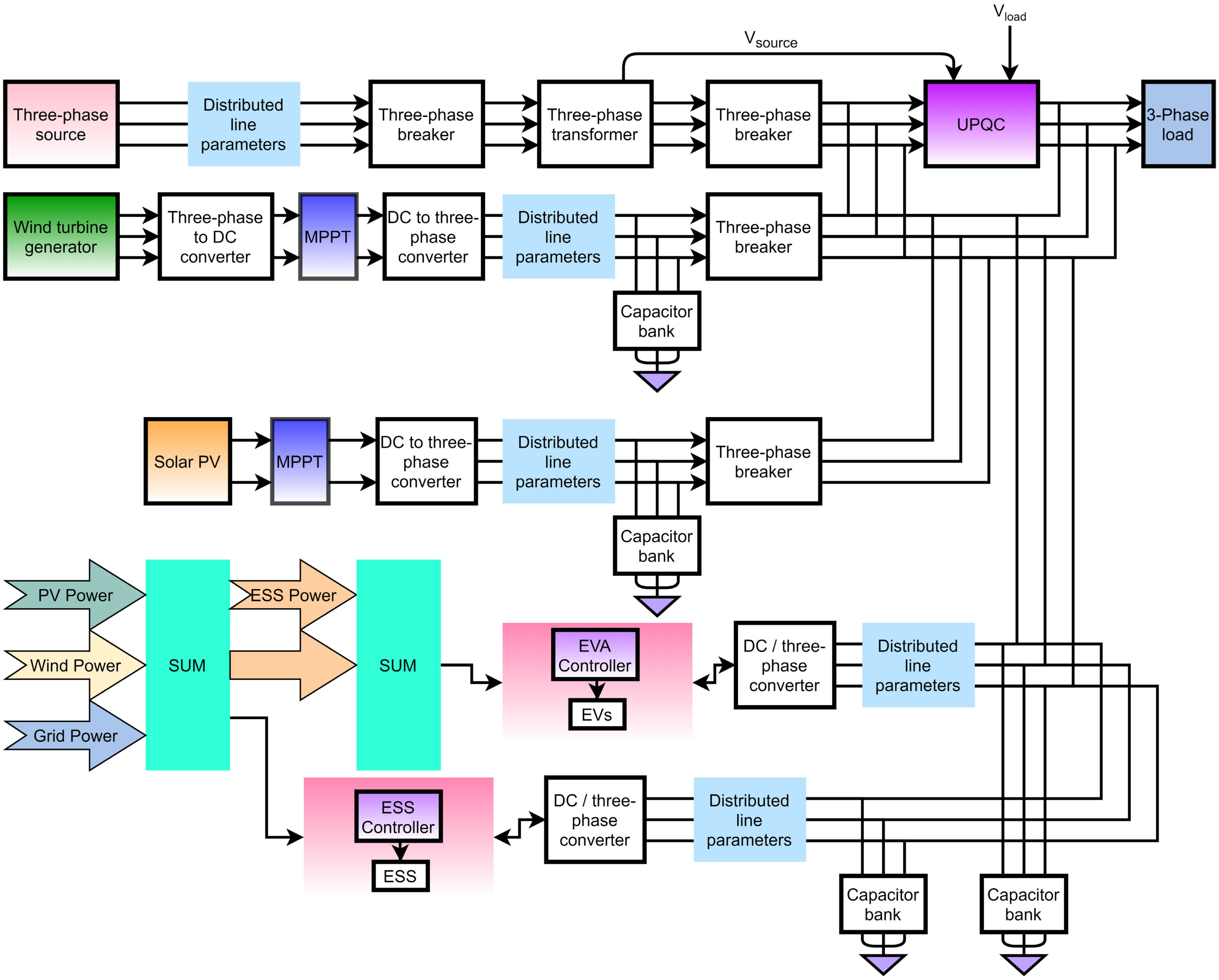


FIGURE 1. **The proposed system including WE generation, solar PV panel, EVs, and ESS connected to the grid.**

- Power enhancement of PV-WE-ESS-EV system.
- Reduction of THD of grid voltages and currents.
- To obtain good voltage regulation at various loading conditions.
- To avail enough power to fulfil the load demand under the worst situation in which RES is not available for power generation.
- To utilize the EVs as ESS during excess availability of power and as power supplier during peak load demand of the grid.

The MPPT algorithm plays an important contribution in generating maximum power at various weather conditions. In this research work, the fuzzy and ANN-based controllers are developed in a MATLAB environment for PV and WE systems. Finally, the simulation results of both the controllers are compared to select the best one.

The EV batteries designed are of 29 kW capacity each (12 V). The battery management system and load balancing with EVs are accomplished by using EVA. The EVA is developed through Fuzzy and ANN for its performance analysis. The grid integration of the hybrid PV-WE system is still a challenging point due to its non-linear characteristics of the power generated through the RESs. The design of controllers for grid integration contains a phase lock loop, voltage regulator, and current regulator, as proposed in this work. The voltage source converter based controller plays a major part in synchronizing RESs into the grid.

The proposed control technique includes PV, WE, ESS, and EVs, which are connected to the grid along with the UPQC-FLC control of the PV-WE-ESS-EV system. This technique cumulatively improves the power quality and reduces the THD values of voltage and current of the grid below the threshold limit provided by ANSI/IEEE-519 (1992) standard.

The FLC and ANN techniques are implemented in the PV-WE-ESS-EV system and the outcomes are compared to get the best technique for achieving improved quality of power, grid voltage, and frequency stabilization. The techniques available in the literature and system of application are summarized in Table 2. The main contributions and findings of this research work are summarized as follows.

- Power is improved and grid stabilization is achieved using UPQC-FLC-EVA.
- The FLC-based MPPT algorithms for PV and WE systems yields better results than ANN-based MPPT algorithms.
- The AI (FLC and ANN)-based EVA controls the bidirectional flow of power (V2G and G2V).
- The AI-based controllers manage the state-of-charge (SoC) and state-of-discharge (SoD) of the ESS and EVs.
- The UPQC provides voltage regulation at various loading conditions (under-loading, overloading, linear and non-linear loadings) and also avoids voltage sag and swell conditions.
- Integrating UPQC, FLC, EVA for improving the overall performance of the system. The integrated technique is termed as UPQC-FLC-EVA.
- Integrating UPQC, ANN, and EVA for comparing the proposed technique with UPQC-ANN-EVA.
- The results of UPQC-FLC-EVA are compared with UPQC-ANN-EVA in terms of power quality improvements and THD reduction and it is observed that FLC-based technique is better in power quality improvement of the proposed system.

III. METHODOLOGY

The work focuses on the power enhancement and grid stabilization of RESs with ESS-EV and non-linear loads. In this Section, the mathematical modeling of solar PV and WE systems are discussed. The MPPT algorithms and design procedure are also provided in this Section.

A. MODELLING OF SOLAR PV SYSTEM

In the literature, many researchers discussed the modeling of PV and designing MPPT algorithms to extract maximum possible power from the PV panel [40]–[45]. The circuit diagram of a simple PV system is shown in Fig. 2. The mathematical equation for the I-V characteristics of the PV panel has been expressed in detail by the authors in [46] and is represented in equation 1. In equation 1, I_L is the current output from the panel, I_{diode} is the current flowing through the diode, I_S is the current from PV panel, the thermal voltage is represented by V_T, c is the diode constant, series and parallel branch resistances are represented by R_{series} and $R_{parallel}$, respectively, and I_{sat} is the reverse saturation current.

$$I_L = I_S - I_{sat}[exp(\frac{V_t + R_{series}I_L}{cV_T} - 1] - \frac{V_t + R_{series}I_L}{R_{parallel}} \quad (1)$$

The block diagram of the PV panel with MPPT algorithm and boost converter is shown in Fig. 3. The drawbacks of conventional MPPT algorithm, including poor performance under non-uniform shading, selection of local maximum point of power under partial irradiation are overcome using the FLC-based MPPT algorithm [47]. In the recent era, FLC is the most preferred technique for the MPPT algorithm. Therefore, FLC-based MPPT is designed in this research study. For controlling a system, process, or a device, fuzzy logic is very useful, simple, robust, and adaptive. It has the capability of making decisions. The block diagram of the fuzzy logic-based MPPT controller is shown in Fig. 4. The first stage in FLC is the fuzzification which converters the values and parameters into the fuzzified form using a function of transformation. The next stage is the interfacing in which the fuzzy rules are set. The last stage is the defuzzification in which the fuzzified parameter is again converted into the crisp form. The parameters used in FLC-based MPPT are PV voltage and current. The power and change in power are evaluated using voltage and current parameters. The controller is a type-2 FLC whose membership function and fuzzy set are given in any form from equations 2,3, and 4 as explained in [47].

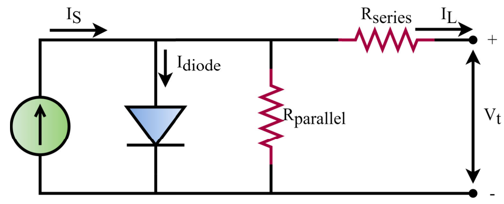


FIGURE 2. Circuit diagram of single solar PV panel.

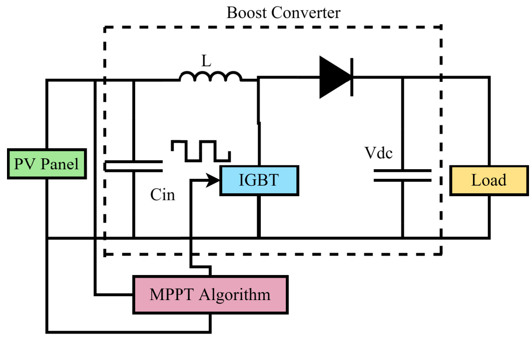


FIGURE 3. MPPT and boost converter used to extract the maximum power output from the PV panel.

$$\tilde{F} = ((y, v), \mu_{\tilde{F}}(y, v))|\forall y \in Y, J_y \subseteq [0, 1] \quad (2)$$

$$\tilde{F} = \int_{y \in Y} \int_{v \in J_y} \frac{\mu_{\tilde{F}}(y, v)}{(y, v)} J_y \subseteq [0, 1] \quad (3)$$

$$\tilde{F} = \sum_{y \in Y} \sum_{u \in J_y} \frac{\mu_{\tilde{F}}(y, v)}{(y, v)} J_y \subseteq [0, 1] \quad (4)$$

In equations 2,3, and 4, $\tilde{F}$ represents the interval type-2 FLC set. This set is defined by a membership function which is also of type-2 represented by $\tilde{F}(y, v)$, where $y \in Y$ and Y is representing the universe of discourse. The expression shown in equation 3 is in continuous form and that of equation 4 is

TABLE 2. Related works and techniques available in the literature for power quality improvement.

Technique	Systems/parameters Considered							
	PV	WE	ESS	EV	Grid	MPPT	Reference	Year
STATCOM		✓			✓	✗	[6]	2020
DVR, DSTATCOM, and FLC-UPQC					✓	✗	[7]	2020
UPQC	✓				✓	✗	[8]	2019
UPFC		✓			✓	✗	[9]	2019
Battery storage		✓	✓		✓	✗	[18]	2008
UPQC-FLC	✓		✓		✓	✗	[27]	2020
UPQC					✓	✗	[28]	2011
UPQC-FLC-EVA	✓	✓	✓	✓	✓	FLC & ANN-based MPPT	Proposed work	

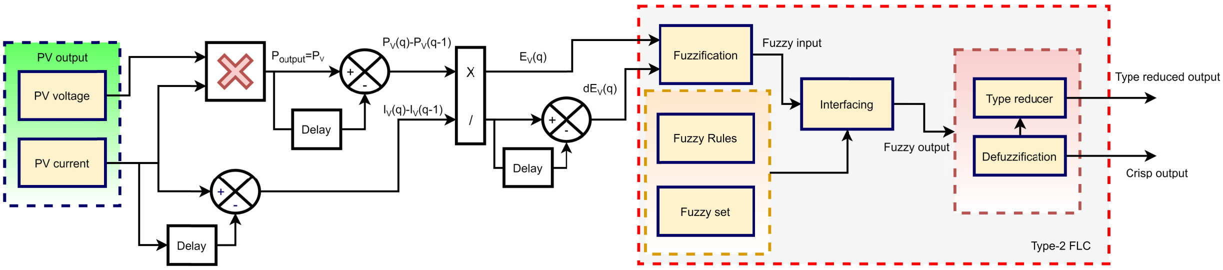


FIGURE 4. Block diagram of interval type-2 FLC-based MPPT controller used to regulate the duty cycle of the boost converter for PV system: Inputs of the interval type-2 FLC are power and current, and the output is the duty ratio to feed to the boost converter.

in discrete form. This FLC interval of type-2 helps to regulate the duty cycle ratio of the boost converter for achieving MPPT as explained in [47]. The error function, which is the ratio of change in power of PV to the change in current of PV, is given in the equation 5. The change in error is given in equation 6.

$$E_V(q) = \frac{P_V(q) - P_V(q-1)}{I_V(q) - I_V(q-1)} \tag{5}$$

$$dE_V(q) = E_V(q) - E_V(q-1) \tag{6}$$

where, $P_V(q)$ and $P_V(q-1)$ are the output power of PV panel at q^{th} and $(q-1)^{th}$ instants respectively. In the same way, $E_V(q)$ and $E_V(q-1)$ are the errors at q^{th} and $(q-1)^{th}$ instants respectively.

B. MODELLING OF WE SYSTEM

The WE has a permanent magnet synchronous generator (PMSG) for power generation from the wind turbines. The PMSG is used because of its advantages over doubly-fed induction generator (DFIG) including greater efficiency, lower cost, easily controllable, and reliable. The mathematical modelling of WE and FLC-based MPPT for the WE system have been provided in many existing literatures [48]–[52]. The mathematical expression of the power output of WE system is expressed in equations 7, 8, 9 and 10.

$$R_{st} = \frac{\omega R_b}{V_w} \tag{7}$$

$$P_{mout} = 0.5\rho\pi R_b^2 C_{pc} V_w^3 \tag{8}$$

$$P_{mout} = T_{mout}\omega \tag{9}$$

$$C_{pc} = (0.44 - 0.0167\theta_p) sin\frac{3.14(N_r-2)}{13-0.3\theta_p}$$

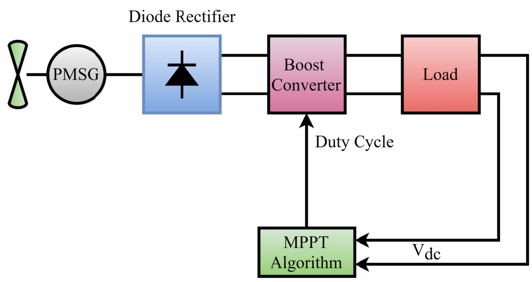


FIGURE 5. Block diagram of WE system along with MPPT controller to extract the maximum, the inputs to the MPPT are dc voltage and current and the output is the duty cycle which is given to the boost converter.

$$- 0.0018(N_r - 2)\theta_p \tag{10}$$

where, R_{st} is the ratio of speed-to-tip, V_w is the speed of the wind, R_b is the radius of blade, ω is the speed of PMSG rotor in radian per second, ρ is the density of air. The coefficient of power is represented as C_{pc}, the mechanical power output is expressed by P_{mout}, torque output is termed as T_{mout}. The pitch angle of the blade is represented as θ_p and the speed ratio is termed as N_r in equation 10. The specifications and the parameters of the PMSG are provided in Table 3. The block diagram of the WE system along with MPPT algorithm is shown in Fig. 5. The MPPT algorithm is based on the FLC technique of type-2 which is shown in Fig. 6.

The membership function and the fuzzy set of the MPPT algorithm for the WE system are expressed in equations 2, 3, and 4. The error function, in this case, is the ratio of change in the power of WE generation to the change in the current of WE generation, which is represented as equation 11. The

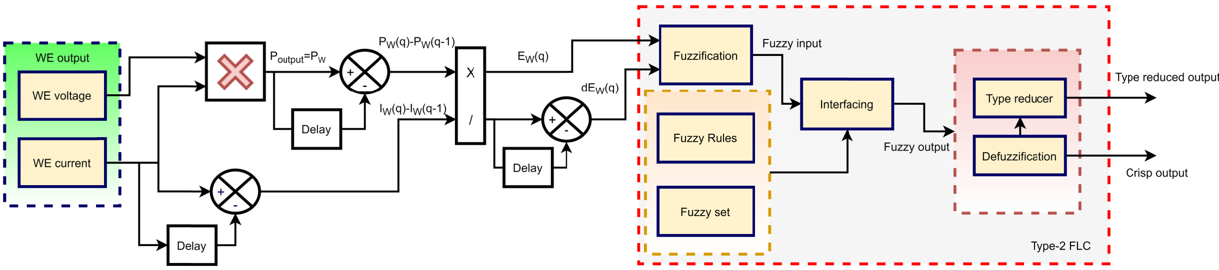


FIGURE 6. Block diagram of interval type-2 FLC-based MPPT controller used to regulate the duty cycle of the boost converter for WE system: Inputs of the interval type-2 FLC are power and current of the WE system, and the output is the duty ratio to feed to the boost converter.

change in error is given in equation 12.

$$E_W(q) = \frac{P_W(q) - P_W(q-1)}{I_W(q) - I_W(q-1)} \tag{11}$$

$$dE_W(q) = E_W(q) - E_W(q-1) \tag{12}$$

The ANN-based MPPT algorithm is developed for tracking the maximum power point from both solar and wind sources. The maximum power output of ANN and FLC-based algorithms for PV and WE are compared and discussed in Section V. The back-propagation method is used to develop the ANN-based MPPT algorithm and to train the developed method. The dc-dc boost converter is controlled to achieve the maximum power point. The three-layer ANN method is used to achieve the maximum power point in the PV system and is shown in fig. 7. The inputs to the neural network are temperature and irradiation. The output of the neural network is the voltage at which the maximum power point is achieved. The model is trained with the sample input and output data using the error back-propagation method to get better performance. For obtaining maximum power, the maximum value of the current is obtained from the V-I characteristics of the PV system. The maximum power is the product of the maximum voltage and the corresponding current value of the V-I curve. When maximum voltage value and the corresponding current are known, the duty cycle of the chopper is obtained from the equation 13 where, V_0, I_0, V_{max}, and I_{max} are representing output voltage, output current, maximum voltage and maximum current from the PV system with dc-dc chopper as shown in fig. 8.

$$D = 1 - \sqrt{\frac{V_{max} \times I_0}{I_{max} \times V_0}} \tag{13}$$

C. MODELLING OF EVA CONTROLLER

It is necessary to satisfy the load demands, and also to maintain the power quality so as to make the grid system reliable and efficient. The ESS system is required to achieve the need for extra power demand and also to store the surplus power. As the solar and wind energy sources are weather, place, and time-dependent, the ESS system is an alternative to these RESs. The ESS system contains battery banks which are subjected to ageing effect, and life degradation issues. Therefore, the ESS system is also less efficient and reliable.

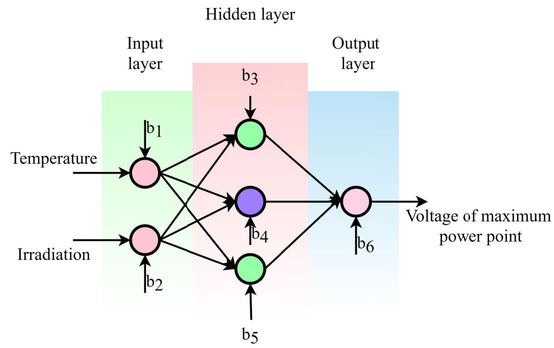


FIGURE 7. Three-layer ANN to achieve maximum power point.

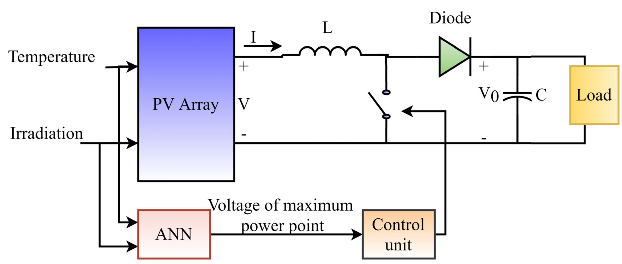


FIGURE 8. ANN-based MPPT for PV system with a dc-dc chopper.

The other major reason is the space occupancy by the battery banks. When the RESs are not available and ESS is discharged, the peak load demand has to be supplied from the grid. The increased load demand and peak duration reduce power quality. Here, the use of EVs come into role. The importance of EVs in RESs connected grid and in green energy utilization have been discussed in detail by the authors [53]. The authors have presented a comparative analysis of various types of EVs considering driving components, energy storage, features, and problems corresponding to each type of EV. The impacts of EVs on the grid, environment, and economy have been also discussed. The negative impacts of EVs include voltage instability, the increased demand for the grid, THD, and voltage sag. These negative impacts of EVs are avoided using FLC-based UPQC in this work. The positive impacts of EVs include V2G, improved, and reliable RESs connected to the grid. The EVs can be scheduled and

TABLE 3. Specifications and parameters of system components.

Parameter	Value	Unit
Rated Power of WE1	30	kW
Rated Power of WE2	30	kW
Total rated power of WE	60	kW
Base wind speed	12	m/s
Pitch angle	0	degree
Stator resistance (per phase)	0.05	Ω
Inductance (armature)	0.000635	H
Inertia	0.011	J
Pole pairs (PMSG)	4	
Grid transformer rating	100	kVA
Grid line-to-line voltage	254.4	V
Frequency of system	50	Hz
Solar PV rating	100	kW
Battery rated capacity	40	kWh
Capacity of each EV	29	kW
Different Loads	50, 55, 60, 70, 90, 100, 150	kW
Load (voltage sag)	50,30,50 (one-phase loose)	kW
Load (voltage swell)	50, 1	kW
Non-linear load	150, (+20,-10)	kW, (kVAR)
Line resistance	2	Ω
Line inductance	0.002	H

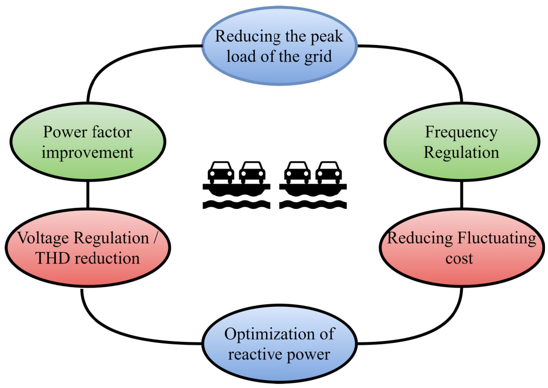


FIGURE 9. Benefits of EVs connected to the grid as ESS when RESs are available in lesser amount.

planned to manage the load power demand and excess power in the grid. For managing the flow of power from V2G and G2V, an EVA is designed, which helps to get improved power quality, reduced THD, and load balancing problem is also removed. The FLC-based ESS-EV system gives better quality of power, also makes the grid-connected PV-WE-ESS-EV system reliable as compared to a simple grid system [54]–[58]. In this work, a battery bank of capacity 40 kWh is used as ESS, and three EV stations are designed having EVs of capacity 29 kW each. The EVA is an intelligent controller designed to control and manage the power flow from V2G and G2V. The benefits of EVs connected to the grid system are mentioned in Fig. 9. The EVA techniques and controls are discussed in [38], [39], [59].

When the ESS-EVs are connected to a grid, voltage regulation is a major concern. The frequency regulation is a major issue in the case of island mode. In the grid connected mode, the frequency does not deviate much. Therefore, the voltage regulation is focused on this work for grid stabilization. The charging and discharging of EVs are decided by the EVA controller. The EVs and ESS battery bank start charging when

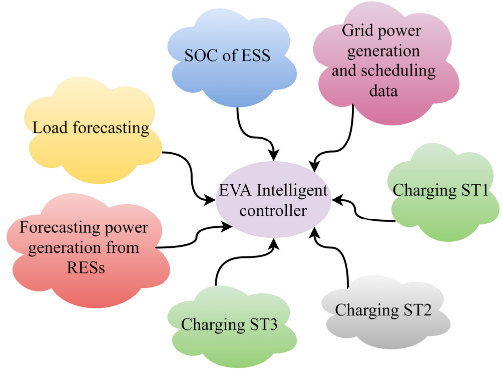


FIGURE 10. EVA intelligent controller and data gathering.

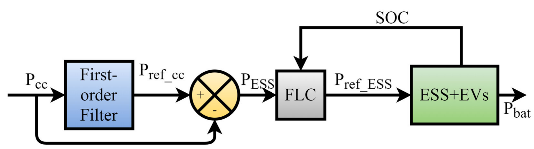


FIGURE 11. FLC-based control of EVs and ESS connected with grid for getting improved power quality.

there is surplus power at the point of common coupling of the grid. The difference between the active power of common coupling and reference load power is estimated and fulfilled by ESS and EVs. The intelligent controller of EVA contains the information from load power, the power generated from RESs, SOC of ESS, and available EVs in the EV stations as shown in Fig. 10. The controller estimates the power required to be supplied from EVs. As per the power requirement from EVs, the number of EVs required to be used as ESS is decided.

The active power at the point of common coupling P_{cc} and the reference power P_{refcc} are evaluated, and the error signal is passed through the FLC. The schematic diagram of the grid-connected system is shown in Fig. 11.

The EVA power management system is developed through Fuzzy and ANN for its performance analysis. The working of the EVA controller is explained through the flow chart shown in Fig. 12. The EVA controller communicates with charging stations (ST1, ST2, and ST3), grid, RESs, and ESS for the exchange of information. In Fig. 12, the charging decision of EVs is made with the help of EVA. The EVs stop at charging stations when not used for travel. These EVs can be used as ESS during peak load time. The cost of charging the EVs stopped at the station for a duration greater than peak load time of the grid is reduced because these are used as ESS. The power supply from EVs to the grid depends on the availability of EVs and SoC of the available EVs. The conditions for SOC and SOD of ESS and EVs are explained in detail in the next section.

D. MODELLING OF UPQC

The problems due to non-linear loads and the problems of power quality, including voltage sag, voltage swell, THD,

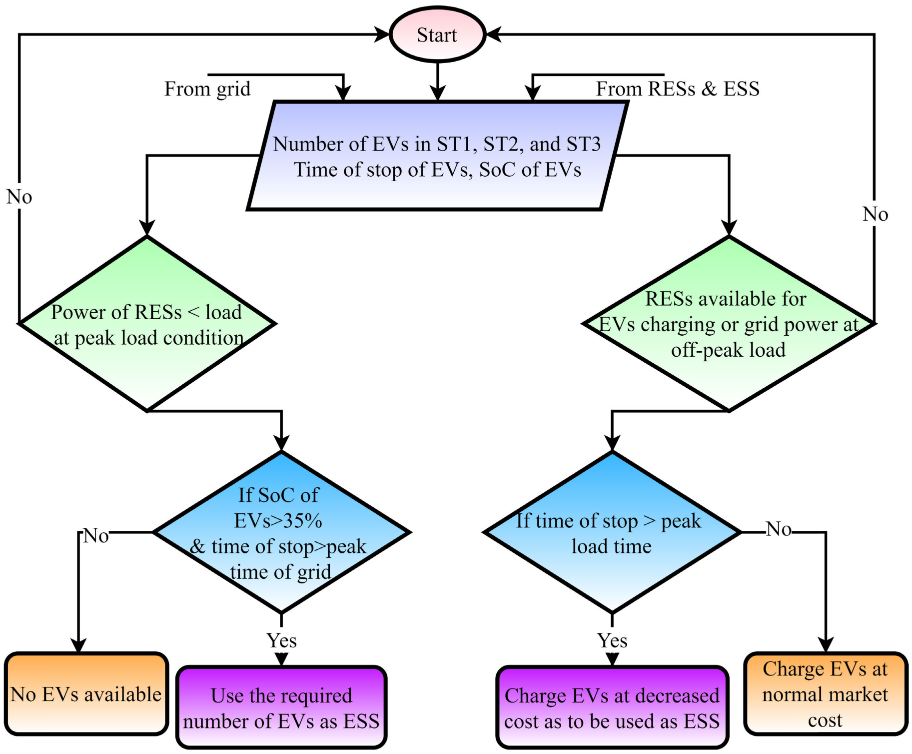


FIGURE 12. Block diagram representation of working of EVA controller.

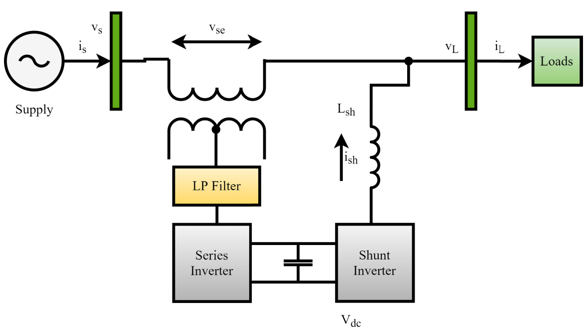


FIGURE 13. Block diagram representation of UPQC having two active inverters connected in series and parallel for power quality improvement.

voltage spike, and unbalance can be avoided by using UPQC. The FLC-based UPQC enhances the grid-connected PV-WE-ESS-EV system with better stability and voltage regulation. The THD value is also maintained lesser than 5% as per the IEEE 519 standard. The block diagram representation of UPQC is given in Fig. 13.

The main objectives of UPQC are series and shunt compensations. The shunt connected inverter balances the source currents by giving negative and zero sequence parts demanded by the load and reduce the THD in the load side current by giving the required current. It also improves the power factor and regulates the dc bus voltage. Another part is a series-connected inverter which balances the voltages at the load side, reduces the THD of the source side voltages, regulates the load bus voltage, and improves the input power factor.

IV. DEVELOPMENT OF FLC-BASED PV-WE-ESS-EV SYSTEM

The control of power flow to the load from different sources available and also from charging-discharging of ESS and EVs in the system is achieved by the use of FLC. The most important part of FLC is the selection of membership functions, rules, input, and output parameters which are shown in Fig. 14. Five membership functions are taken in this work named as very low, low, medium, high, and very high (full). The input parameters for FLC are SOC of ESS, SOC of the battery bank in EV charging stations, load forecasted data, and power generation data from PV-WE. The outputs of FLC are charging-discharging of ESS, EV charging stations, load power management from RESs, and grid. The developed FLC algorithm for power flow management and charging-discharging of ESS and EVs is illustrated in Fig. 15.

The main objective of the FLC algorithm is to utilize the power generated from the RESs and stored energy of ESS and EVs for achieving the economical operation of the system during peak load demand. This way the power quality is improved and grid load demand is balanced. The system performance is dependent on the load condition and availability of different sources of supply.

During peak load demand, if the power generated from RESs is larger than the load demand then ESS is charged if the

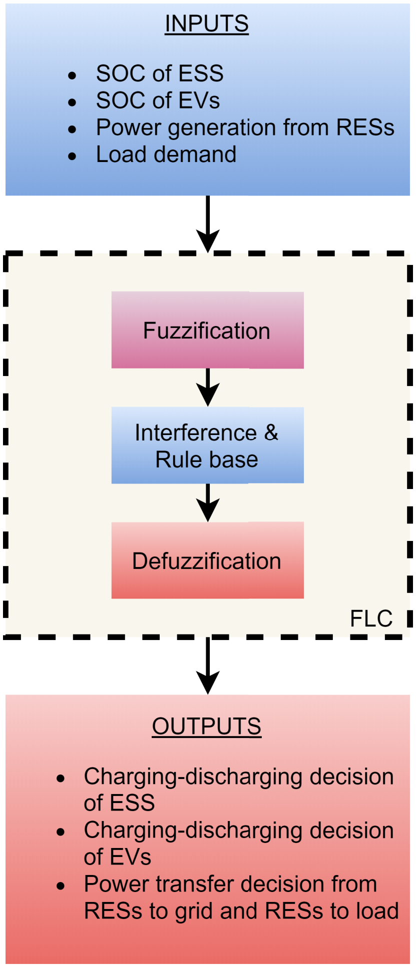


FIGURE 14. FLC-based control of PV-WE-ESS-EV system.

SOC of ESS is lesser than 98%. If the battery is fully charged and the SOC of EVs are lesser than 98% then, the EVs are charged. In case when both ESS and available EVs are fully charged, the surplus power from RESs is sent to the grid. If the power generated from RESs is lesser than the load demand and SOC of ESS is greater than 35%, the load is supplied power from the RESs and the ESS. If the SOC of ESS is lesser than 35% or if the summation of power from RESs and ESS is lesser than the load then, the EVs are discharged (if SOC of EVs is greater than 35%). If excess EV power is available, ESS is charged when the SOC of ESS is lesser than 35%. In case when both ESS and EVs are discharged, power is supplied from the grid to the load, and the excess loads are removed under worst-case when none of RESs, ESS, and EVs is available.

During off-peak load, if the power generated from the RESs is greater than the load power and the SOC of ESS is lesser than 98%, the ESS is charged. When the ESS is fully-charged, the EVs are charged if the SOC of EVs is lesser than 98%. If both ESS and EVs are fully charged, the surplus power from RESs is sent to the grid. In case when the power generated from the RESs is lesser than the load demand, the power is supplied from the grid to satisfy the load demand as it will not cost more during off-peak time as compared to the peak time power cost. The ESS and EVs are also charged from the grid power during off-peak load if the SOCs are lesser than 98% because the ESS and EVs should be fully-charged and prepared for the peak load demand of the grid.

V. RESULTS AND DISCUSSION

The proposed work focuses on the power enhancement and harmonic reduction for the PV-WE-ESS-EV system connected to the grid. The UPQC is able to handle the non-linear and different undesired types of loads. The whole system is refreshed and checked by FLC in every 0.01 second. In this Section, the outcomes of the two techniques are discussed. The first is based on FLC, and the second one is based on the ANN approach. It is observed that FLC is giving better results as compared to ANN to achieve maximum power from the PV-WE system, to get good voltage regulation, and to reduce the THD values of voltages and currents. Also, ANN requisites learning data and time to perform better and accurate. The learning of ANN techniques is time-consuming and also need various historical data to learn from them.

A. ROLE OF EVA IN PV-WE-ESS-EV SYSTEM

To get a reliable power transfer system and quality improvement of power, EVs play an important role in the grid-connected RESs. During the availability of excess power from RESs, the charging of EVs will cost lesser which is a potential benefit for the customer, and during the deficiency of power at the grid due to increased load or unavailability of RESs, the cost of charging the EVs will be high. If EVs are used to supply power to the grid during the peak demand of the grid, it will be treated as an ESS system.

The control of power flow from V2G and G2V is decided by the EVA. It also decides the number of EVs required at a particular time to charge or discharge. This makes the PV-WE-ESS-EV system reliable and improves the quality of power. The power needed to be supplied from EVs to the grid is given by equation 14. The number of EVs to be connected at a particular time is decided by evaluating the power required P_{EVA}.

$$P_{EVA} = P_L - P_{res} \tag{14}$$

where, P_{EVA} is the power requirement of the grid to be fulfilled by the EVs. This power is evaluated by the EVA taking the difference of load power demand, P_L, and power generated by the RESs, P_{res}. The load voltage and current are improved by providing the required power from the EVs in the case of the unavailability of PV-WE. For the validation of the proposed technique, different loading conditions are applied for a different time interval. The load voltage and current when PV-WE generation is not enough for the load demand is shown in Fig. 16a under different loading conditions. During the short period of 0 to 5 s, the PV-WE are not available in sufficient amount to fulfil the load demand, and the grid power is also less. At this condition, the voltage

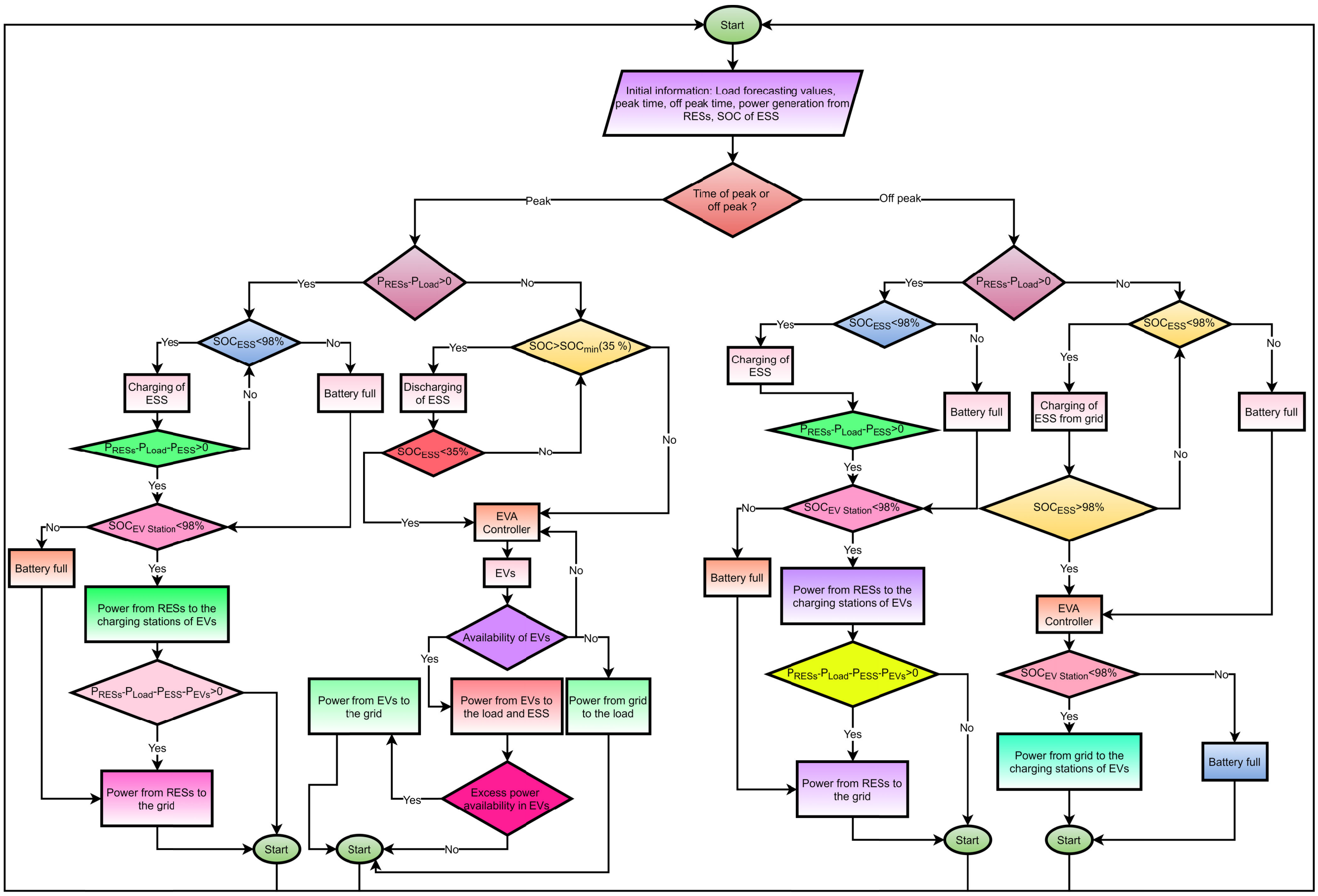


FIGURE 15. Detailed diagram of the FLC algorithm indicating the power flow of PV-WE-ESS-EV system.

and current are shown clearly in Fig. 17a for the period of 0 to 2.5s. The voltage and current have distortions; therefore, THD values are high.

The qualities of voltage and current are improved on adding the EVs to the grid as shown in Fig. 16b. The excess load demand is evaluated by the EVA and the number of EVs to be connected to the grid is decided accordingly. These connected EVs fulfil the extra load demand of the grid. The quality of voltage and current for a time span of 0 to 2.5 is clearly shown in Fig. 17b. In this Fig., it is seen that the addition of EVs improves the voltage and current qualities, reduces the THD values of voltage and current, and hence, the power quality is improved.

The THD values of load voltage without adding EVA are found to be 9.72%, 1.44%, 9.75%, and 1.09% during the time spans of 0-1.25s, 1.25-2.5s, 2.5-3.5s, and 3.5-5s respectively. The THD values are high in this case because of the over-loading condition. After EVA comes into action, these THD values are reduced drastically as 2.27%, 1.20%, 1.93%, and 1.00% during the time span of 0-1.25s, 1.25-2.5s, 2.5-3.5s, and 3.5-5s respectively. These reductions in THD result in improving the quality of power and performance of the grid-connected RES. The comparative analysis of THDs of load voltage and current of PV-WE-ESS system with and without EVA is provided in Section VI.

B. POWER IMPROVEMENT WITH UPQC-FLC-EVA

The EVA provides the excess power demand to the grid and the UPQC helps to improve the voltage and current qualities. The FLC controls the PV-WE-ESS-EV system. The three-dimensional plot of rules of FLC for MPPT of the PV panel is shown in Fig. 18. The duty ratio is changed to achieve MPPT of power output. The dc output voltage of the PV panel and dc current output of the PV panel are used as inputs to the FLC-based MPPT algorithm. The algorithm outputs the duty cycle value to get the point of maximum power. The output power of the PV solar panel is shown in Fig. 19. The maximum power output taken from the PV system is 80 kW out of 100 kW, which is the capacity of the PV panel. The output is shown for a short span of time (0.5 s). The steady-state power is achieved at 0.0375 s and therefore, there is a power drop observed during transient state before reaching the steady-state power output.

The wind turbine output of one WE system of capacity 30 kW is shown in Fig. 20 with respect to turbine speed at various wind speeds. The range of wind speed

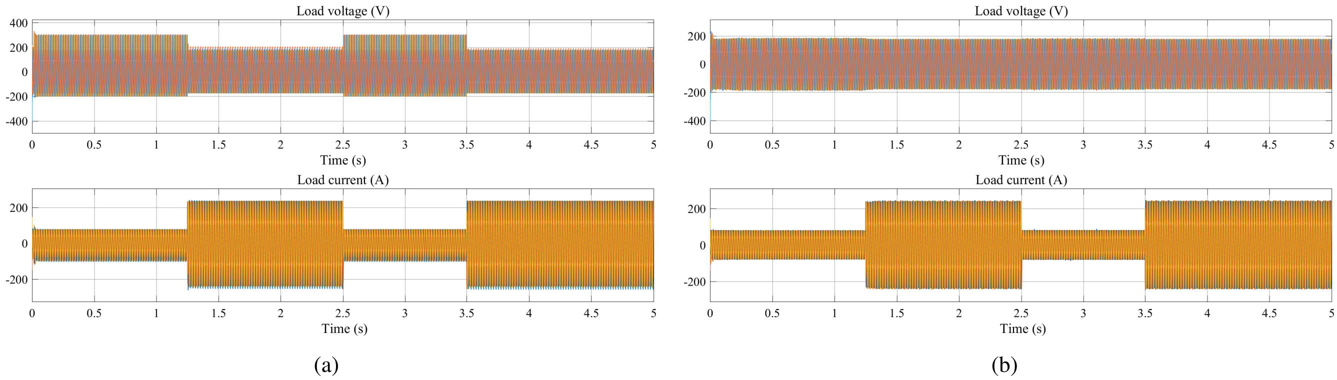


FIGURE 16. (a) Voltage and current quality under unavailability of PV-WE and without the addition of EVs (The waveforms are distorted), and (b) Voltage and current quality under unavailability of PV-WE and with the addition of EVs (Waveform quality is improved).

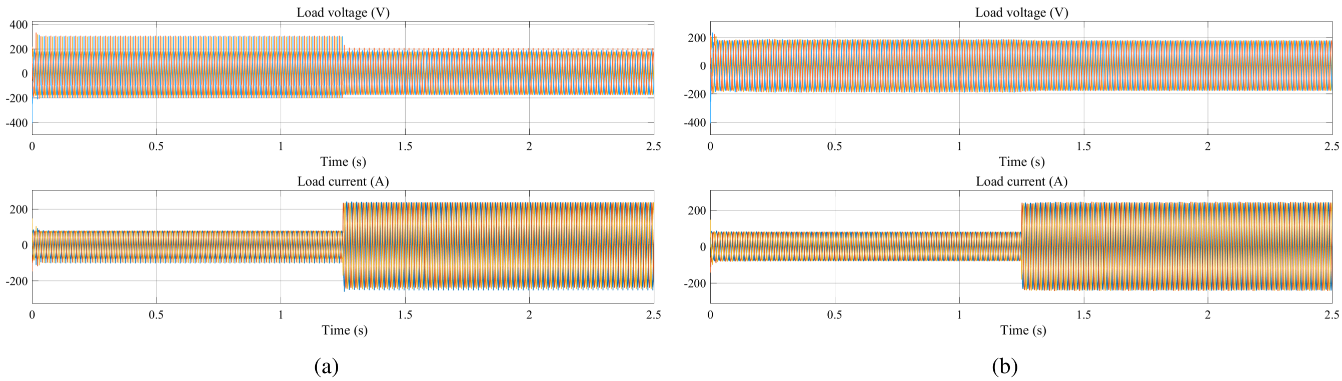


FIGURE 17. (a) Voltage and current of load side without EVA under the availability of PV-WE in lesser amount for time span 0 to 2.5 s shows high distortions in the different loading conditions, and (b) Voltage and current of load side with EVA under the availability of PV-WE in lesser amount for time span 0 to 2.5 s. The load power is fulfilled and the waveforms of voltage and current are improved under different loading conditions.

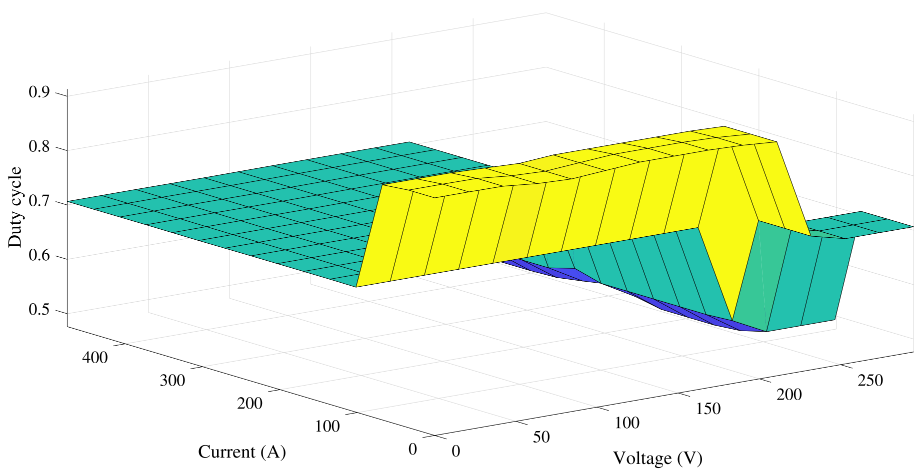


FIGURE 18. Three-dimensional plot of FLC for MPPT of the PV panel. The controller takes voltage and current as inputs and gives duty ratio as output to the boost converter to track the maximum power.

is from 6 m/s to 14.4 m/s at pitch angle $\beta = 0\,\text{deg}$. The output power of the single WE system with the FLC-based MPPT controller is shown in Fig. 21. The FLC-based MPPT controller has a better ability to track the maximum powerpoint.

The input voltage and current of the grid are shown in Fig. 22. The THD of source-side voltage is shown in Fig. 23, which gives the THD value of 1.70 %. The load voltage under different loading conditions is shown in Fig. 24a, 24b, 24c, and 24d. Voltage and current waveforms

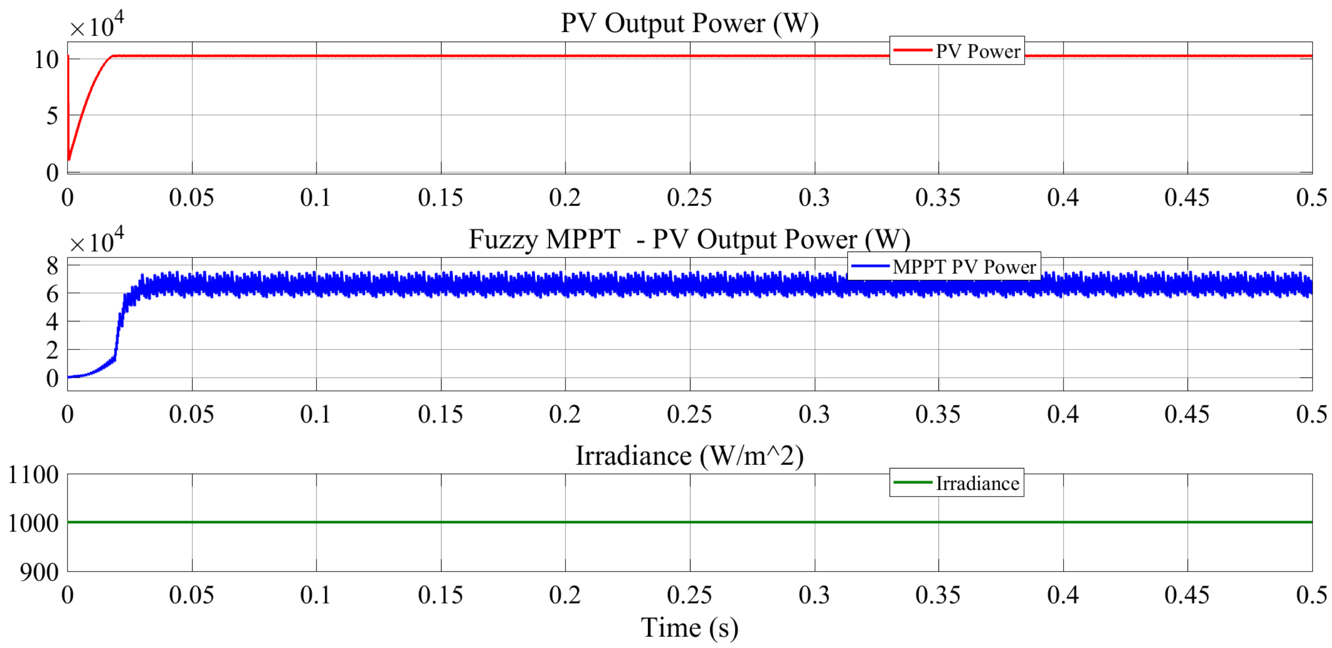


FIGURE 19. FLC-based MPPT for PV: Output power of PV panel at irradiation of 1000 W/m^2.

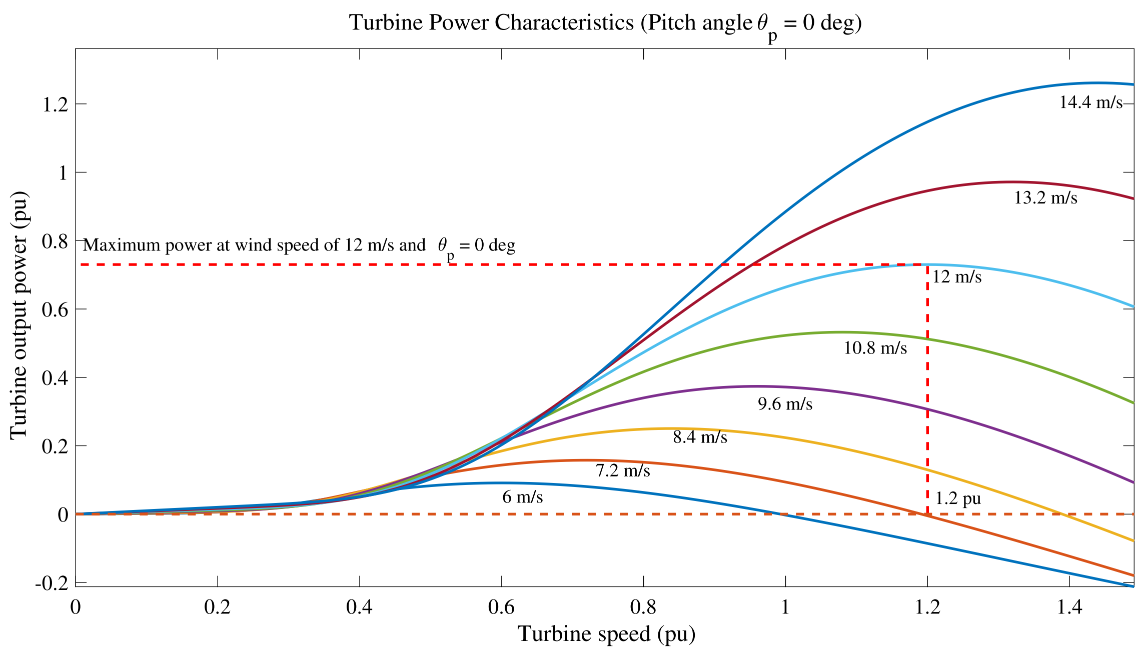


FIGURE 20. FLC-based MPPT for WE: output power of single WE with respect to wind speed.

of load side under loading condition causing voltage sag to the load voltage is shown in Fig. 24a. On using UPQC-FLC-EVA, the UPQC maintains the voltage quality improved under different load conditions and avoid voltage sag with the help of ESS and EVA. The voltage sag is caused due to a sudden increase in load or due to a loose connection of load. In Fig. 24a, the load connected from time 0 to 0.3 seconds is 50 kW. From time 0.3 to 0.5 seconds, the unbalanced load is connected which causes the voltage sag but due to UPQC, the voltage profile is maintained constant and the quality of voltage is not affected. The voltage swell is caused due to a sudden decrease in load. In Fig. 24b, the load at 0.3 second is decreased abruptly which causes voltage swell but the quality of voltage is again not affected due to UPQC, ESS, and EVs. Similarly, the voltage and current under-loading, overloading, linear and non-linear loading are shown in Fig. 25a and 25b

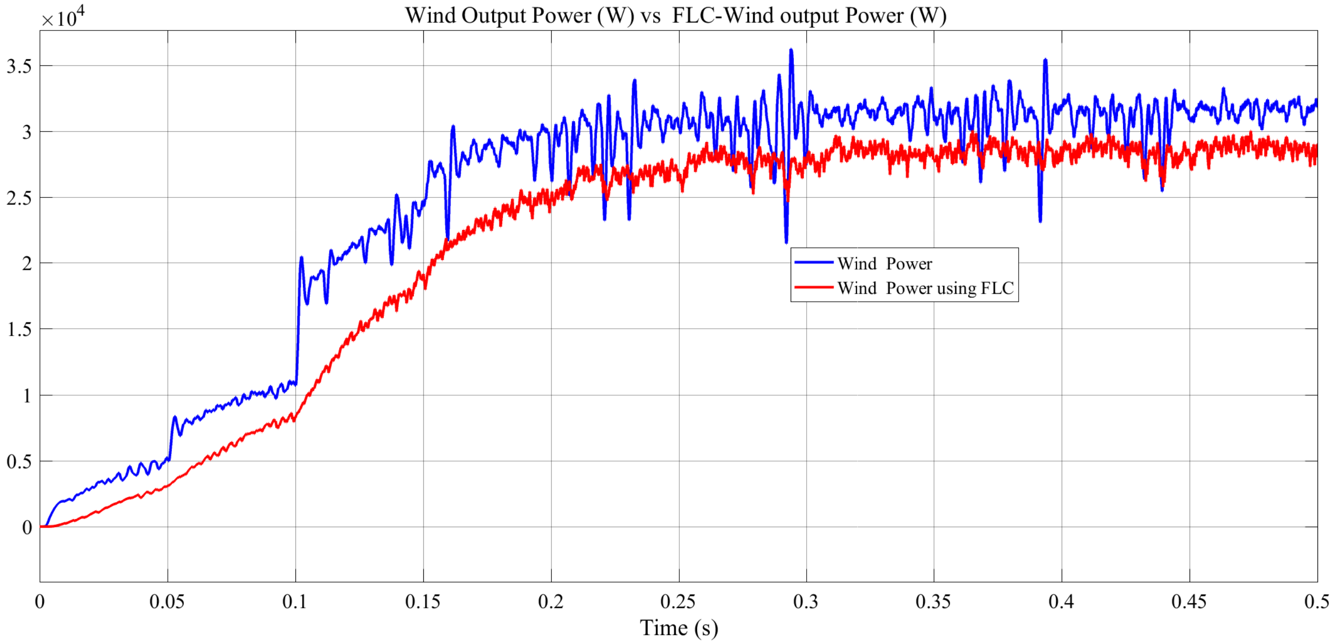


FIGURE 21. Output power of FLC-MPPT based WE and simple MPPT-power output of WE. The output power of FLC-MPPT is better than simple MPPT.

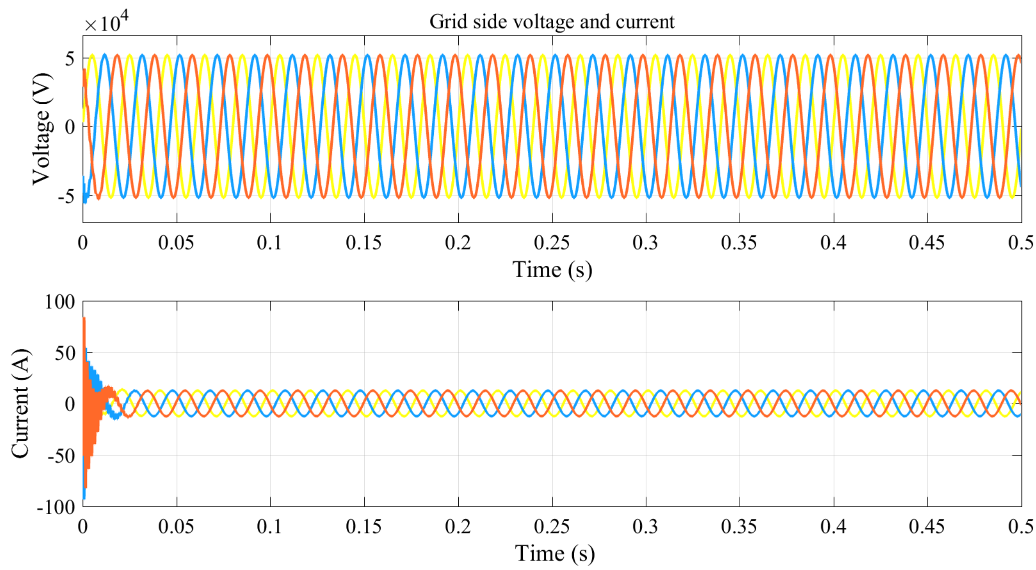
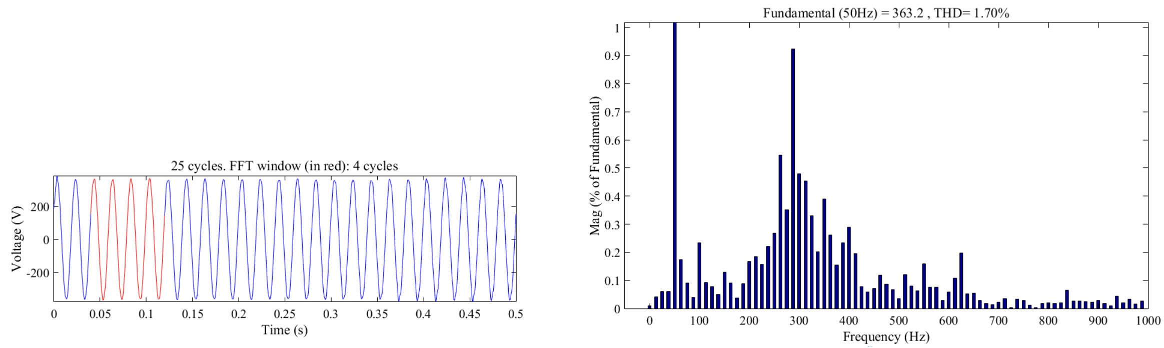


FIGURE 22. Voltage and current waveforms of the source side of the grid.

respectively. The THD details of voltage and current signals of source and load sides under different loading conditions are discussed in the next section. From Fig. 24a to 25b, it is clear that on changing the load condition, the voltage magnitude and characteristics do not change much. Hence, FLC-based UPQC, along with the ESS-EVA system, improves the power quality and also reduces the THD as discussed in the next section.

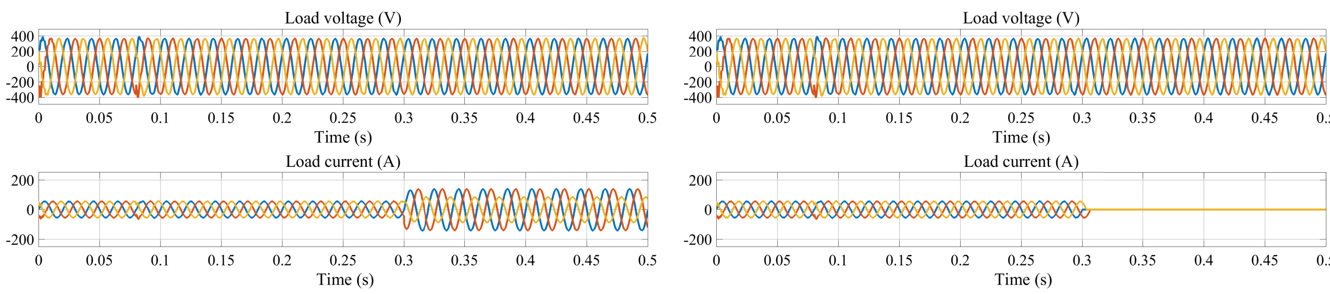
C. POWER IMPROVEMENT WITH UPQC-ANN-EVA

The ANN-based controller also gives better performance in power enhancement and THD reduction. The demerits associated with ANN are the need for strong learning from historical data, and time consumption for learning. The technique used for controlling the complicated grid system should be fast and accurate. In this work, a two-layer neural network has been designed to model the controller. The output power of the PV panel at an irradiation value of 1000 W/m^2 is shown in Fig. 26. In this output, it is observed that the MPPT power output is lesser as compared to FLC-based MPPT. The output power of WE using the ANN-based MPPT algorithm is presented in Fig. 27. The load voltage under different loading conditions is shown in Fig. 28a, 28b, 29a, and 29b. The voltage quality is kept almost constant by the UPQC, ESS, and EVA under different loading conditions in the case



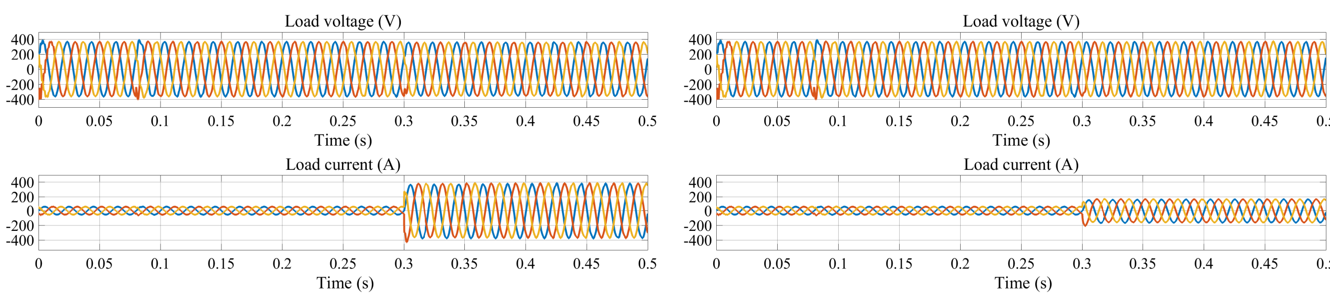
(a) (b)

FIGURE 23. **(a) Voltage signal of the source side, and (b) THD of source side voltage of the grid in % of 50 Hz.**



(a) (b)

FIGURE 24. **(a) Voltage and current waveforms of load side under loading condition causing voltage sag to the load voltage. On using UPQC-FLC-EVA, the UPQC maintains the voltage quality improved under load condition of voltage sag which is avoided using the ESS and EVA, and (b) Voltage and current waveforms of load side under-voltage swell. The UPQC maintains the voltage quality by improving the voltage swell using the ESS and EVA.**



(a) (b)

FIGURE 25. **(a) Voltage and current waveforms of load side under under-loading and overloading conditions of the grid using UPQC-FLC-EVA, and (b) Voltage and current waveforms of load side under linear and non-linear loading conditions of the grid using UPQC-FLC-EVA.**

of the ANN technique also. The comparative analysis of THD values of load voltage under different loading conditions is provided in the next section. The power outputs from PV and WE systems using UPQC-ANN-EVA technique are lesser as compared with UPQC-FLC-EVA technique.

D. POWER MANAGEMENT IN THE PROPOSED SYSTEM

The power flow condition between the various components of the proposed system is explained in Fig. 15 in Section IV. During peak load, when the net power output of RESs (P_{res} is lesser than the load demand (P_L) as shown in Fig. 30a, the ESS is discharged if the SOC of ESS is greater than 35% as shown in Fig. 30b. The available EVs are also treated as ESS to fulfil the peak load demand and to improve the power quality. When the load is at peak values of 150kW and 160kW, and the sum of power generated from RESs is lesser than the peak load, the ESS and EVs are discharging. During off-peak load, when P_{res} is greater than the load demand as shown in Fig. 31a from time instant 0.02 to 0.06 seconds, the ESS is charged from the surplus power of RESs if SoC of ESS is lesser than 98%. If the SoC of ESS is higher than 98%, the EVs are charged if available during this off-peak

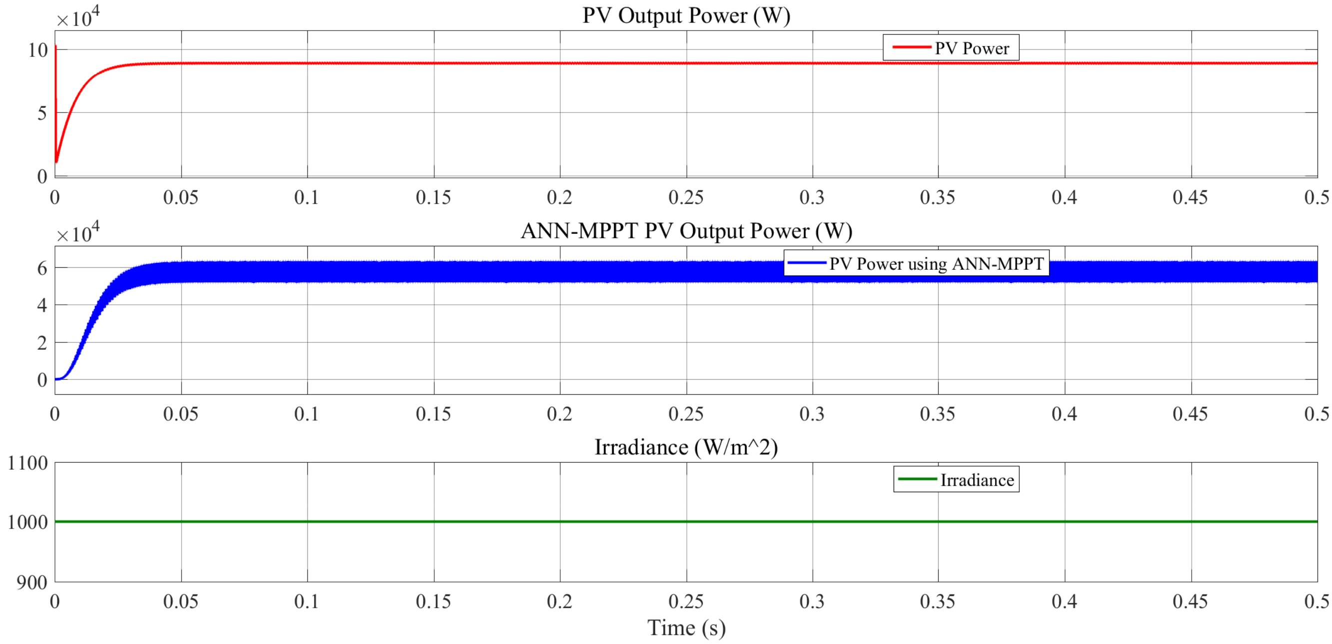


FIGURE 26. PV output power, power output of ANN-based MPPT at irradiation of 1000 W/m^2.

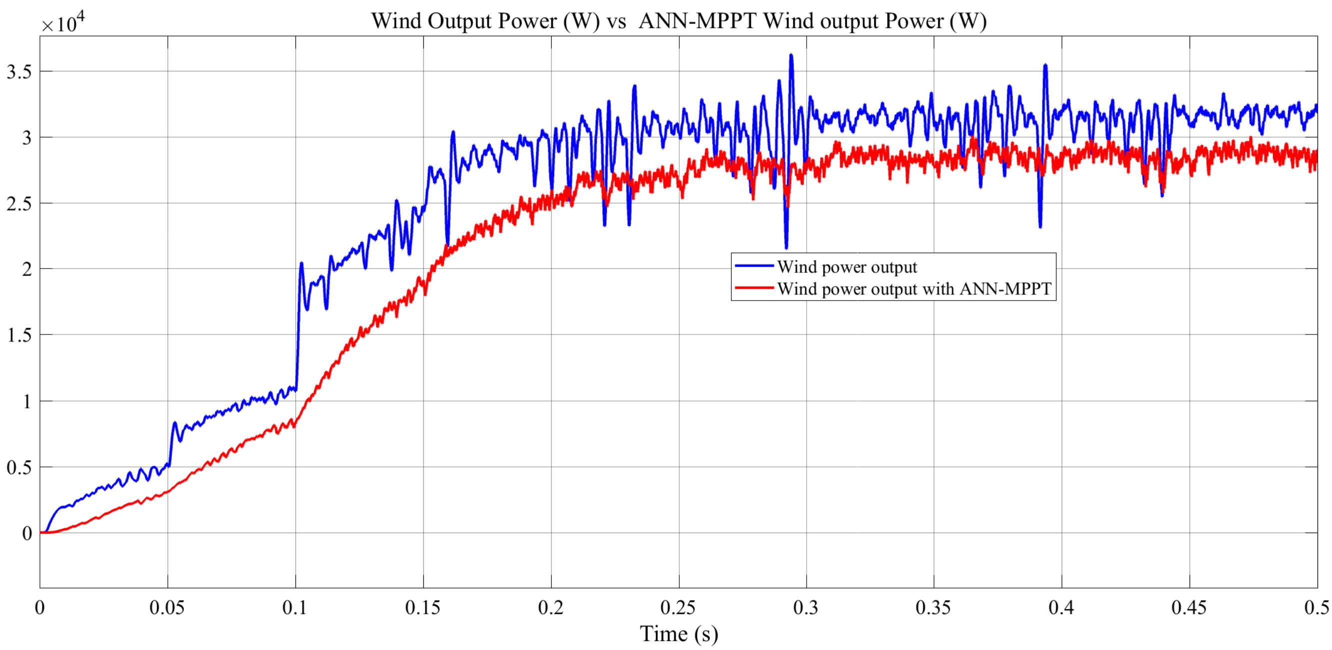
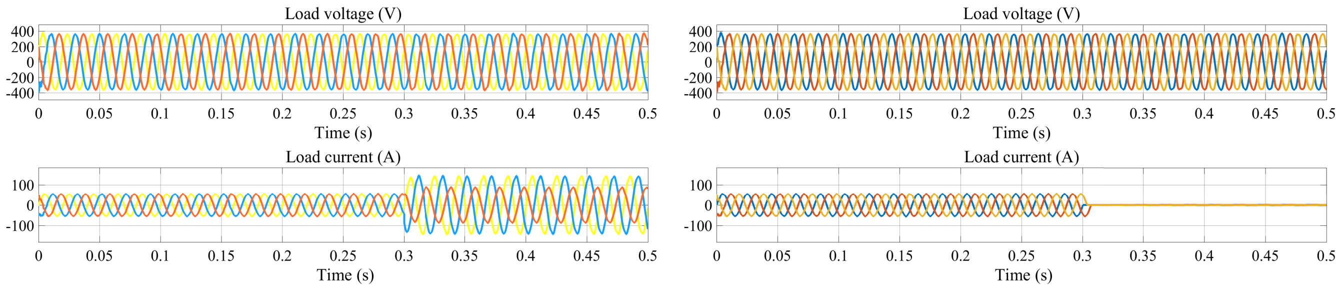


FIGURE 27. Nominal WE output power and ANN-MPPT WE output power.

load condition. When the P_{res} is lesser than the off-peak load, then also the ESS and EVs are charged if the SoC of ESS and EVs are less than 98% as shown in Fig. 31b. In this case, if the P_{res} is not enough to charge ESS and EVs, the ESS and EVs are charged using the grid power as the cost of power is least during off-peak hours. In Fig. 32a, the ESS is not charged completely therefore, during surplus power availability from RESs, the ESS is charged from the power output of RESs as shown in Fig. 32b. If the surplus power is not available, the ESS is charged from the grid because charging ESS during off-peak load costs less. Also, the ESS should be fully charged to handle the peak load condition of the grid.

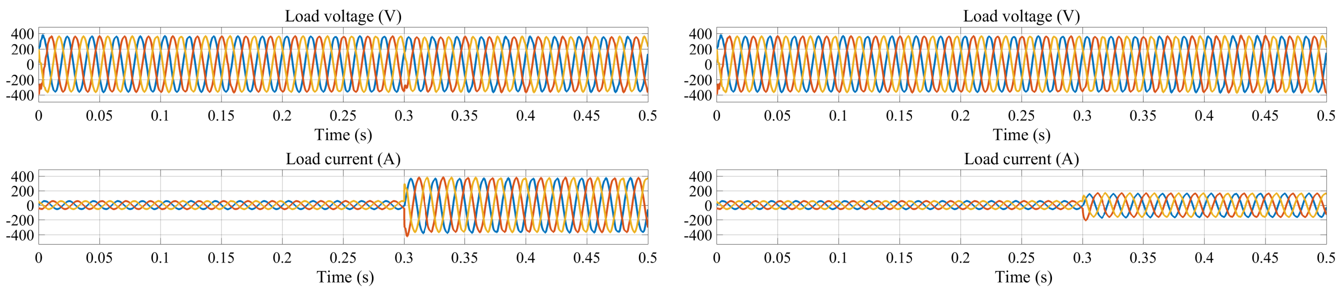
VI. COMPARATIVE ANALYSIS

The addition of EVs and EVA in PV-WE-ESS system makes the RESs more reliable as discussed in Section V-A. The comparison of THD values of load voltage and current under



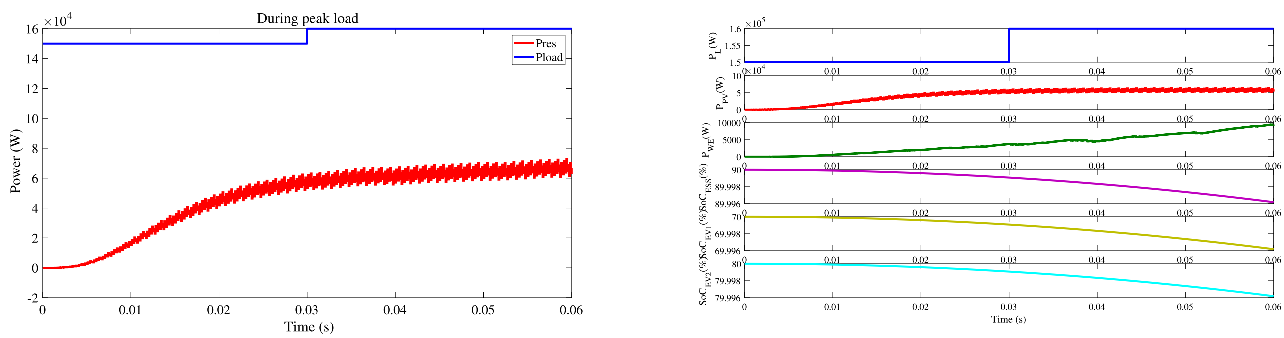
(a) (b)

FIGURE 28. **(a) Voltage and current waveforms of load side under loading condition causing voltage sag to the load voltage. On using UPQC-ANN-EVA, the UPQC maintains the voltage quality improved under load condition of a voltage sag with the help of ESS and EVA, and (b) Voltage and current waveforms of load side under voltage swell which is improved using UPQC-ANN-EVA.**



(a) (b)

FIGURE 29. **(a) Voltage and current waveforms of load side under under-loading and overloading conditions of the grid using UPQC-FLC-EVA, and (b) Voltage and current waveforms of load side under linear and non-linear loading conditions of the grid using UPQC-FLC-EVA.**

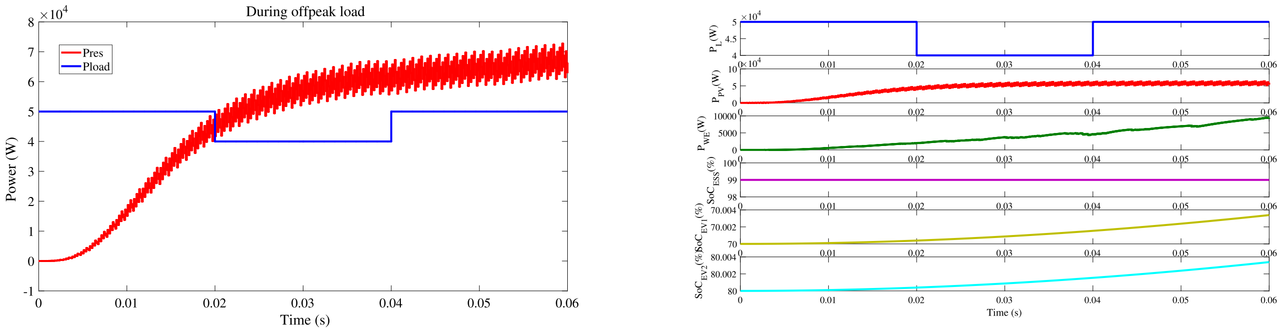


(a) (b)

FIGURE 30. **(a) The net power output from RESs and load demand of the grid during a peak load condition, and (b) The net power output from RESs and load demand of the grid during off-peak load condition with ESS in discharging condition, the EVs available during peak load are helpful to maintain the quality of the power.**

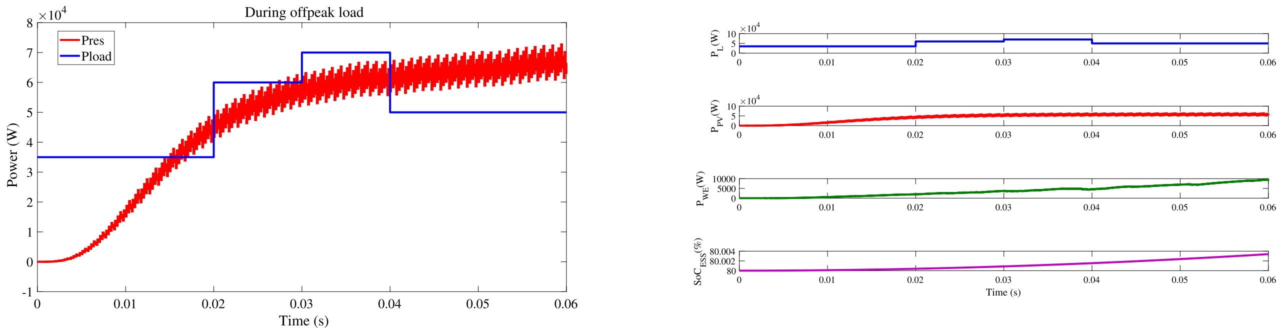
two cases (with and without EVs) is summarized in Table 4. Table 4 shows that when RESs are least available, the integration of EVs reduces the THD and improves the power quality. In this Section, the outcomes of PV-WE-ESS-EV system using UPQC-FLC-EVA and UPQC-ANN-EVA are compared for selecting the better one. The comparison of PV output power using ANN and FLC-based MPPT algorithms is shown in Fig. 33a. It is seen that the PV output power using MPPT based on-FLC is better than that of using the ANN-based MPPT algorithm. The comparison of WE output power is illustrated in Fig. 33b. In this case, the power outputs from WE using FLC-based MPPT and ANN-based MPPT are similar. A very little difference is there, but even in such little difference, the FLC-MPPT yields better results as compared to ANN-MPPT.

The THD reduction using the techniques based on ANN and FLC are compared for different loading conditions and summarized in Tables 5, 6, 7, 8, and 9. On using UPQC-FLC-EVA, the THD values of voltages and currents of both load side and source side are under 5%, which is the acceptable limit as per IEEE-519 (1992) standard. In the case of UPQC-ANN-EVA, the THD values of grid-side voltage



(a) (b)

FIGURE 31. (a) The net power output from RESs and load demand of the grid during an off-peak load condition, and (b) The net power output from RESs and load demand of the grid during off-peak load condition with ESS full-charged.



(a) (b)

FIGURE 32. (a) The net power output from RESs and load demand of the grid during off-peak load condition, and (b) The net power output from RESs and load demand of the grid during off-peak load condition with 80% charge of ESS.

TABLE 4. Comparative Analysis of THD values during less availability of PV-WE with and without EVs.

Parameter	Unit	0-1.25s	1.25-2.5s	2.5-3.5s	3.5-5s	% THD without EV	% THD with EV
Load voltage	V	✓				9.72	2.27
			✓			1.44	1.20
				✓		9.75	1.93
					✓	1.09	1.00
Load current	A	✓				5.75	1.97
			✓			1.23	0.90
				✓		5.73	1.70
					✓	1.26	0.92

TABLE 5. Comparative Analysis of THD values during underloading conditions using ANN and FLC.

Controller	Grid voltage	Load voltage	Grid current	Load current	Unit
ANN	3.04	0.57	3.08	0.57	%
Fuzzy	2.69	0.47	2.72	1.62	%

TABLE 6. Comparative Analysis of THD values during normal loading conditions using ANN and FLC.

Controller	Grid voltage	Load voltage	Grid current	Load current	Unit
ANN	5.43	2.09	5.49	2.35	%
Fuzzy	4.77	0.86	4.82	2.36	%

TABLE 7. Comparative Analysis of THD values during overloading conditions using ANN and FLC.

Controller	Grid voltage	Load voltage	Grid current	Load current	Unit
ANN	5.85	1.14	5.91	4.37	%
Fuzzy	3.89	0.74	3.93	3.63	%

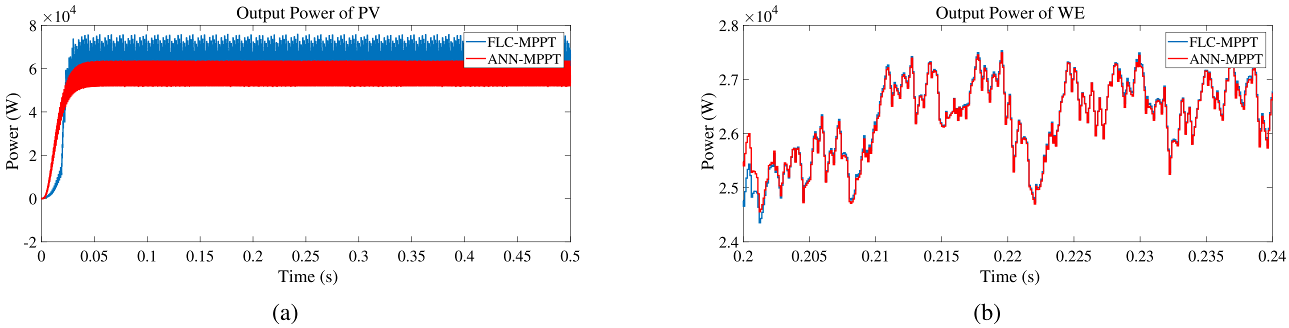


FIGURE 33. (a) PV output power using ANN-MPPT and FLC-MPPT. The FLC-MPPT is giving better performance than ANN-MPPT in extracting maximum power from PV, and (b) WE output power using ANN-MPPT and FLC-MPPT. In this case, both ANN and FLC-based MPPT are giving similar performance but the performance of FLC-MPPT is better as it is giving output power greater than the ANN-MPPT by some watts.

TABLE 8. Comparative Analysis of THD values during voltage sag loading using ANN and FLC.

Controller	Grid voltage	Load voltage	Grid current	Load current	Unit
ANN	2.39	2.39	6.45	1.62	%
Fuzzy	2.37	2.37	6.27	1.62	%

TABLE 9. Comparative Analysis of THD values during voltage swell loading using ANN and FLC.

Controller	Grid voltage	Load voltage	Grid current	Load current	Unit
ANN	2.06	2.07	6.81	6.67	%
Fuzzy	2.02	2.07	6.38	6.31	%

during normal loading and overloading are found to be greater than 5%, which is not acceptable for the voltage range of the system under consideration. The THD values of load voltage under sag and swell conditions are also observed to be lesser than 5% whereas the THD of load current and source current is higher than 5% due to sudden increase and decrease in load during sag and swell condition. The FLC is showing better THD reduction for grid voltage and current under all loading conditions. The THD values of load side current under normal and under loading conditions using FLC are greater than that of ANN. This difference is acceptable for FLC as it is giving much better performance for THD reduction for other voltages and current.

From the comparative analysis of ANN and FLC based controllers, it is observed that FLC is giving a better performance to get the maximum possible output power from PV and WE. The addition of EVs increased the reliability and quality of power of the grid and the connected PV-WE system. The UPQC-FLC-EVA technique helps to enhance the quality of power of the grid by reducing the THD in source and load side voltages and currents, by giving extra power support from EVs, extracting maximum power from PV and WE systems, and by providing improved voltage regulation during different loading conditions.

VII. CONCLUSION AND SCOPES FOR FUTURE WORK

The authors have proposed a technique for the power enhancement of the PV-WE-ESS-EV system using FLC and UPQC controllers. The FLC-based MPPT algorithms are designed for PV and WE to extract maximum power. The UPQC provides the voltage regulation support for different loading conditions. An EVA algorithm has been developed to provide load balancing and support to the weather-dependent PV and WE systems by connecting the required number of EVs. The proposed PV-WE-ESS-EV system ensures the grid system reliability and enhances the power quality of the system because of EVs addition to the grid. It is also observed that the distortions in voltage and current waveforms are avoided using the UPQC-FLC-EVA technique. The THD of load and source-side voltages and currents are obtained and are lesser than 5% using the proposed technique, which fulfils the threshold limit of THD as per the IEEE-519 (1992) standard. Conclusively, the performance of the UPQC-FLC-EVA technique has overcome the ANN-based controlling technique. The work performed in this research can be extended for the following future works.

- Optimized operation of EVA in terms of cost.
- ANFIS-based control of the PV-WE-ESS-EV system.
- Other machine learning-based algorithms to control and manage the power flow.

LIST OF ACRONYMS

AI	Artificial Intelligence
ANN	Artificial Neural Network
BSS	Battery Storage System
DSTATCOM	Distribution Static Compensator
DVR	Dynamic Voltage Restoration
EVA	Electric Vehicle Aggregator
FLC	Fuzzy Logic Controller

FACTS	Flexible Alternating Current Transmission System
GUPFC	Generalized UPFC
G2V	Grid to Vehicle
MPPT	Maximum Power Point Tracking
NN	Neural Network
PV	Photovoltaic
PI	Proportional Integral
P_{EVA}	Power from EVs
P_L	Load power
P_{res}	Net power generated from RESs
RESs	Renewable Energy Sources
STATCOM	Static Compensator
SOC	State of Charge
SOD	State-of-Discharge
SVC	Static Var Compensator
THD	Total Harmonic Distortion
UPFC	Unified Power Flow Controller
UPQC	Unified Power Quality Conditioner
V2G	Vehicle to Grid
WE	Wind Energy

ACKNOWLEDGMENT

The authors wholeheartedly thank the Department of Electrical Engineering, Indian Institute of Technology (Banaras Hindu University), Varanasi, Uttar Pradesh, India for providing the laboratory related facilities to accomplish the research work in time. They also would like to thank Dr. Irfan Ahmad Khan, Clean and Resilient Energy Systems Laboratory, Texas A&M University, Galveston, USA for the technical expertise provided.

REFERENCES

[1] R. M. Elavarasan, "The motivation for renewable energy and its comparison with other energy sources: A review," *Eur. J. Sustain. Develop. Res.*, vol. 3, no. 1, p. em0076, Feb. 2019.

[2] R. M. Elavarasan, "Comprehensive review on India's growth in renewable energy technologies in comparison with other prominent renewable energy based countries," *J. Sol. Energy Eng.*, vol. 142, no. 3, pp. 1–11, 2020.

[3] R. Madurai Elavarasan, S. Afridhis, R. R. Vijayaraghavan, U. Subramaniam, and M. Nurunnabi, "SWOT analysis: A framework for comprehensive evaluation of drivers and barriers for renewable energy development in significant countries," *Energy Rep.*, vol. 6, pp. 1838–1864, Nov. 2020.

[4] R. Madurai Elavarasan, L. Selvamanohar, K. Raju, R. R. Vijayaraghavan, R. Subburaj, M. Nurunnabi, I. A. Khan, S. Afridhis, A. Hariharan, R. Pugazhendhi, U. Subramaniam, and N. Das, "A holistic review of the present and future drivers of the renewable energy mix in Maharashtra, state of India," *Sustainability*, vol. 12, no. 16, p. 6596, Aug. 2020.

[5] G. M. Shafiullah, M. T. Arif, and A. M. T. Oo, "Mitigation strategies to minimize potential technical challenges of renewable energy integration," *Sustain. Energy Technol. Assessments*, vol. 25, pp. 24–42, Feb. 2018.

[6] L. Ashok Kumar and V. Indragandhi, "Power quality improvement of grid-connected wind energy system using facts devices," *Int. J. Ambient Energy*, vol. 41, no. 6, pp. 631–640, May 2020.

[7] S. A. Mohamed, "Enhancement of power quality for load compensation using three different FACTS devices based on optimized technique," *Int. Trans. Electr. Energy Syst.*, vol. 30, no. 3, p. e12196, Mar. 2020.

[8] S. Paramanik, K. Sarker, D. Chatterjee, and S. K. Goswami, "Smart grid power quality improvement using modified UPQC," in *Proc. Devices for Integr. Circuit (DevIC)*, Mar. 2019, pp. 356–360.

[9] S. Shetty, H. Suresh, M. Sharanappa, and C. V. Ramesh, "Performance of wind energy conversion system during fault condition and power quality improvement of grid-connected WECS by FACTS (UPFC)," in *Emerging Research in Computing, Information, Communication and Applications*. Springer, 2019, pp. 211–225.

[10] T.-U. Hassan, R. Abbassi, H. Jerbi, K. Mehmood, M. F. Tahir, K. M. Cheema, R. M. Elavarasan, F. Ali, and I. A. Khan, "A novel algorithm for MPPT of an isolated PV system using push pull converter with fuzzy logic controller," *Energies*, vol. 13, no. 15, p. 4007, Aug. 2020.

[11] M. Rajvikram, P. Renuga, and M. Swathisriranjani, "Fuzzy based MPPT controller's role in extraction of maximum power in wind energy conversion system," in *Proc. Int. Conf. Control, Instrum., Commun. Comput. Technol. (ICCICCT)*, Dec. 2016, pp. 713–719.

[12] R. M. Elavarasan, A. Ghosh, T. K. Mallick, A. Krishnamurthy, and M. Saravanan, "Investigations on performance enhancement measures of the bidirectional converter in PV–wind interconnected microgrid system," *Energies*, vol. 12, no. 14, p. 2672, 2019.

[13] R. Krishnamoorthy, K. Udhayakumar, R. Kannadasan, R. M. Elavarasan, and L. Mihet-Popa, "An assessment of onshore and offshore wind energy potential in India using moth flame optimization," *Energies*, vol. 13, no. 12, p. 3063, 2020.

[14] A. T. Kiani, M. F. Nadeem, A. Ahmed, I. Khan, R. M. Elavarasan, and N. Das, "Optimal PV parameter estimation via double exponential function-based dynamic inertia weight particle swarm optimization," *Energies*, vol. 13, no. 15, p. 4037, Aug. 2020.

[15] Y. Mahmoud, W. Xiao, and H. H. Zeineldin, "A simple approach to modeling and simulation of photovoltaic modules," *IEEE Trans. Sustain. Energy*, vol. 3, no. 1, pp. 185–186, Jan. 2012.

[16] M. E. Glavin, P. K. W. Chan, S. Armstrong, and W. G. Hurley, "A standalone photovoltaic supercapacitor battery hybrid energy storage system," in *Proc. 13th Int. Power Electron. Motion Control Conf.*, Sep. 2008, pp. 1688–1695.

[17] A. M. Knight and G. E. Peters, "Simple wind energy controller for an expanded operating range," *IEEE Trans. Energy Convers.*, vol. 20, no. 2, pp. 459–466, Jun. 2005.

[18] T. Aboul-Seoud and J. Jatskevich, "Improving power quality in remote wind energy systems using battery storage," in *Proc. Can. Conf. Electr. Comput. Eng.*, May 2008, pp. 001743–001746.

[19] P. Nema, R. K. Nema, and S. Rangnekar, "A current and future state of art development of hybrid energy system using wind and PV-solar: A review," *Renew. Sustain. Energy Rev.*, vol. 13, no. 8, pp. 2096–2103, Oct. 2009.

[20] H. Yang, L. Lu, and W. Zhou, "A novel optimization sizing model for hybrid solar-wind power generation system," *Sol. Energy*, vol. 81, no. 1, pp. 76–84, Jan. 2007.

[21] F. Giraud and Z. M. Salameh, "Analysis of the effects of a passing cloud on a grid-interactive photovoltaic system with battery storage using neural networks," *IEEE Trans. Energy Convers.*, vol. 14, no. 4, pp. 1572–1577, Dec. 1999.

[22] A. Nottrott, J. Kleissl, and B. Washom, "Energy dispatch schedule optimization and cost benefit analysis for grid-connected, photovoltaic-battery storage systems," *Renew. Energy*, vol. 55, pp. 230–240, Jul. 2013.

[23] Z. Shu and P. Jirutitijaroen, "Optimal operation strategy of energy storage system for grid-connected wind power plants," *IEEE Trans. Sustain. Energy*, vol. 5, no. 1, pp. 190–199, Jan. 2014.

[24] S.-K. Kim, J.-H. Jeon, C.-H. Cho, J.-B. Ahn, and S.-H. Kwon, "Dynamic modeling and control of a grid-connected hybrid generation system with versatile power transfer," *IEEE Trans. Ind. Electron.*, vol. 55, no. 4, pp. 1677–1688, Apr. 2008.

[25] R. A. Badwawi, M. Abusara, and T. Mallick, "A review of hybrid solar PV and wind energy system," *Smart Sci.*, vol. 3, no. 3, pp. 127–138, Jan. 2015.

[26] K. Mahmud, M. J. Hossain, and G. E. Town, "Peak-load reduction by coordinated response of photovoltaics, battery storage, and electric vehicles," *IEEE Access*, vol. 6, pp. 29353–29365, 2018.

[27] A. Amirullah, U. B. Surabaya, A. Adiananda, O. Penangsang, A. Soeprijanto, U. B. Surabaya, I. T. S. Nopember, and I. T. S. Nopember, "Load active power transfer enhancement using UPQC-PV-BES system with fuzzy logic controller," *Int. J. Intell. Eng. Syst.*, vol. 13, no. 2, pp. 329–349, Apr. 2020.

[28] V. Khadkikar, "Enhancing electric power quality using UPQC: A comprehensive overview," *IEEE Trans. Power Electron.*, vol. 27, no. 5, pp. 2284–2297, May 2012.

[29] S. Devassy and B. Singh, "Design and performance analysis of three-phase solar PV integrated UPQC," *IEEE Trans. Ind. Appl.*, vol. 54, no. 1, pp. 73–81, Jan. 2018.
[30] S. K. Dash and P. K. Ray, "Power quality improvement utilizing PV fed unified power quality conditioner based on UV-PI and PR-R controller," *CPSS Trans. Power Electron. Appl.*, vol. 3, no. 3, pp. 243–253, Sep. 2018.
[31] J. Jayachandran and R. Murali Sachithanandam, "Performance investigation of unified power quality conditioner using artificial intelligent controller," *Int. Rev. Model. Simul.*, vol. 8, no. 1, p. 48, Feb. 2015.
[32] K. R. Rao and K. S. Srikanth, "Improvement of power quality using fuzzy logic controller in grid connected photovoltaic cell using UPQC," *Int. J. Power Electron. Drive Syst.*, vol. 5, no. 1, p. 101, Jul. 2014.
[33] P. Nunes and M. C. Brito, "Displacing natural gas with electric vehicles for grid stabilization," *Energy*, vol. 141, pp. 87–96, Dec. 2017.
[34] P.-Y. Kong and G. K. Karagiannidis, "Charging schemes for plug-in hybrid electric vehicles in smart grid: A survey," *IEEE Access*, vol. 4, pp. 6846–6875, 2016.
[35] C. Chellaswamy and R. Ramesh, "Future renewable energy option for recharging full electric vehicles," *Renew. Sustain. Energy Rev.*, vol. 76, pp. 824–838, Sep. 2017.
[36] G. Wenzel, M. Negrete-Pincetic, D. E. Olivares, J. MacDonald, and D. S. Callaway, "Real-time charging strategies for an electric vehicle aggregator to provide ancillary services," *IEEE Trans. Smart Grid*, vol. 9, no. 5, pp. 5141–5151, Sep. 2018.
[37] X. Zhu, H. Han, S. Gao, Q. Shi, H. Cui, and G. Zu, "A multi-stage optimization approach for active distribution network scheduling considering coordinated electrical vehicle charging strategy," *IEEE Access*, vol. 6, pp. 50117–50130, 2018.
[38] D. Kosmanos, L. A. Maglaras, M. Mavrovouniotis, S. Moschoyiannis, A. Argyriou, A. Maglaras, and H. Janicke, "Route optimization of electric vehicles based on dynamic wireless charging," *IEEE Access*, vol. 6, pp. 42551–42565, 2018.
[39] T. U. Solanke, V. K. Ramachandaramurthy, J. Y. Yong, J. Pasupuleti, P. Kasinathan, and A. Rajagopalan, "A review of strategic charging–discharging control of grid-connected electric vehicles," *J. Energy Storage*, vol. 28, Apr. 2020, Art. no. 101193.
[40] S. Ravikumar and H. Vennila, "Hybrid wind-solar system—An optimised approach for efficient power generation," *Int. J. Comput. Aided Eng. Technol.*, vol. 13, nos. 1–2, pp. 154–167, 2020.
[41] K. Javed, H. Ashfaq, and R. Singh, "A new simple MPPT algorithm to track MPP under partial shading for solar photovoltaic systems," *Int. J. Green Energy*, vol. 17, no. 1, pp. 48–61, Jan. 2020.
[42] S. Bhattacharyya, D. S. K. Patnam, S. Samanta, and S. Mishra, "Steady output and fast tracking MPPT (SOFT MPPT) for P&O and InC algorithms," *IEEE Trans. Sustain. Energy*, early access, May 6, 2020, doi: 10.1109/TSTE.2020.2991768.
[43] J. Kim and H. Cha, "A novel voltage control MPPT algorithm using variable step size based on P&O method," *Trans. Korean Inst. Power Electron.*, vol. 25, no. 1, pp. 29–36, 2020.
[44] M. M. Rahman and M. S. Islam, "PSO and ANN based hybrid MPPT algorithm for photovoltaic array under partial shading condition," *Eng. Int.*, vol. 8, no. 1, pp. 9–24, Apr. 2020.
[45] R. Kumar M, S. Satya Narayana, and G. Vulasala, "Advanced sliding mode control for solar PV array with fast voltage tracking for MPP algorithm," *Int. J. Ambient Energy*, vol. 41, no. 10, pp. 1192–1200, Aug. 2020.
[46] H. Bellia, R. Youcef, and M. Fatima, "A detailed modeling of photovoltaic module using MATLAB," *NRIAG J. Astron. Geophysics*, vol. 3, no. 1, pp. 53–61, Jun. 2014.
[47] P. Verma, R. Garg, and P. Mahajan, "Asymmetrical interval type-2 fuzzy logic control based MPPT tuning for PV system under partial shading condition," *ISA Trans.*, vol. 100, pp. 251–263, May 2020.
[48] R. Tiwari and N. R. Babu, "Fuzzy logic based MPPT for permanent magnet synchronous generator in wind energy conversion system," *IFAC-PapersOnLine*, vol. 49, no. 1, pp. 462–467, 2016.
[49] Y. Saidi, A. Mezouar, Y. Miloud, B. Brahmi, K. D. E. Kerrouche, and M. A. Benmahdjoub, "Adaptive maximum power control based on optimum torque method for wind turbine by using fuzzy-logic adaption mechanisms during partial load operation," *Periodica Polytechnica Electr. Eng. Comput. Sci.*, vol. 64, no. 2, pp. 170–178, Jan. 2020.
[50] Q.-V. Ngo, C. Yi, and T.-T. Nguyen, "The maximum power point tracking based-control system for small-scale wind turbine using fuzzy logic," *Int. J. Electr. Comput. Eng.*, vol. 10, no. 4, pp. 3927–3935, 2020.
[51] B. Rached, M. Elharoussi, and E. Abdelmounim, "Design and investigations of MPPT strategies for a wind energy conversion system based on doubly fed induction generator," *Int. J. Electr. Comput. Eng. (IJECE)*, vol. 10, no. 5, p. 4770, Oct. 2020.
[52] H. Bouazza, M. L. Bendaas, T. Allaoui, and M. Denai, "Application of artificial intelligence to wind power generation: Modelling, control and fault detection," *Int. J. Intell. Syst. Technol. Appl.*, vol. 19, no. 3, pp. 280–305, 2020.
[53] F. Un-Noor, S. Padmanaban, L. Mihet-Popa, M. Mollah, and E. Hossain, "A comprehensive study of key electric vehicle (EV) components, technologies, challenges, impacts, and future direction of development," *Energies*, vol. 10, no. 8, p. 1217, Aug. 2017.
[54] H. Zhao, Q. Wu, C. Wang, L. Cheng, and C. N. Rasmussen, "Fuzzy logic based coordinated control of battery energy storage system and dispatchable distributed generation for microgrid," *J. Mod. Power Syst. Clean Energy*, vol. 3, no. 3, pp. 422–428, Sep. 2015.
[55] S. Sinha and P. Bajpai, "Power management of hybrid energy storage system in a standalone DC microgrid," *J. Energy Storage*, vol. 30, Aug. 2020, Art. no. 101523.
[56] F. J. Vivas, F. Segura, J. M. Andújar, A. Palacio, J. L. Saenz, F. Isorna, and E. López, "Multi-objective fuzzy logic-based energy management system for microgrids with battery and hydrogen energy storage system," *Electronics*, vol. 9, no. 7, p. 1074, Jun. 2020.
[57] J. Hu, D. Liu, C. Du, F. Yan, and C. Lv, "Intelligent energy management strategy of hybrid energy storage system for electric vehicle based on driving pattern recognition," *Energy*, vol. 198, May 2020, Art. no. 117298.
[58] R. Bindu and S. Thale, "Power management strategy for an electric vehicle driven by hybrid energy storage system," *IETE J. Res.*, pp. 1–11, Mar. 2020, doi: 10.1080/03772063.2020.1729257.
[59] F. Gao, L. Zhu, M. Shen, K. Sharif, Z. Wan, and K. Ren, "A blockchain-based privacy-preserving payment mechanism for vehicle-to-grid networks," *IEEE Netw.*, vol. 32, no. 6, pp. 184–192, Nov. 2018.

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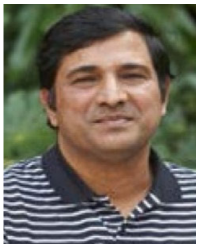

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