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Improving the Performance of Hybrid System-Based Renewable Energy by Artificial Intelligence

Research paper

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Abstract: Artificial intelligence (AI) has emerged as a critical indicator of technological progress in recent years. The present study uses AI to enhance the efficiency of a hybrid system that operates on renewable energy sources. The hybrid system we propose consists of a wind energy conversion system (WECS), a photovoltaic system (PVS), a battery storage system (BSS) and electronic power converters. AI manages these converters cleverly. We use the maximum power point tracking (MPPT)-based fuzzy logic controller (FLC) to regulate the boost converter in the PVS and the WECS. We propose an adaptive neuro fuzzy inference system (ANFIS)-based controller to control the bidirectional converter of the storage system. The design of this module intends to maintain voltage stability on the direct current (DC) bus and improve energy quality. We study and simulate this system using MATLAB/SIMULINK. The results of this research show that the FLC-MPPT technique outperforms the Perturb and Observe (P&O) algorithm in terms of efficiency in power production. The console we propose also shows good results in maintaining the voltage stability in the DC bus in comparison with the proportional integral (PI) controller. This paper has the potential to contribute to the development of environmentally friendly resource performance.

Keywords: *AI • MPPT • performance • hybrid system • converter*

1. Introduction

In the backdrop of the diminishing supply of fossil fuels as well as their escalating prices and the environmental harm caused by their emissions, the adoption of renewable energies will be important in the forthcoming years (Bouchebbat and Gherbi, 2017; Boutabba et al., 2021). This adoption will be fostered due to the presence of numerous renewable energy sources, including wind, solar, marine and hydroelectric power. Wind and solar energy are the most prevalent sources of renewable energy, primarily because they are widely accessible and relatively simple to utilise (Kumar et al., 2020; Mahesh and Sandhu, 2015). Renewable energy resources can be utilised within localised or autonomous networks to supply energy for agricultural purposes and also to meet the energy needs of isolated locations such as military barracks, islands and distant rural regions that lack access to electrical grids (Shammari et al., 2023; Yahyaoui and de la Peña, 2022). Energy storage system (ESS) accession plays a vital role in renewable energy systems due to the intermittent and unexpected nature of photovoltaic (PV) and wind generators in addition to the changing demand for loads (Alagammal et al., 2023; Wu et al., 2016). Variable weather conditions, such as wind speed, solar radiation and temperature, cause the efficiency of wind power systems and photovoltaic systems (PVSs) to change. This is why maximum power point tracking (MPPT)-based direct current (DC)/DC converters are used to maximise the energy produced from both sources (Gozim et al., 2018).

Several MPPT technologies for solar systems and wind power systems have been found in the literature, such as 'P&O.FLC.ANN.' In Dursun and Kulaksiz. (2020), the authors have provided a Perturb and Observe (P&O)-based MPPT for the control of small-sized permanent magnet synchronous generator (PMSG)-based wind energy conversion system (WECS) in two different cases of wind speed variation. The results of this work have shown

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that the maximum amount of energy produced can be utilised. However, the known defects of this algorithm are deviation and the apparent oscillation in the results. In Villalva and Ruppert. (2009) an MPPT-based P&O was introduced to control the PVS and improve its performance. The results of this work showed modest performance. This algorithm also featured a clear defect, which was deviation and oscillation at the maximum power point. In Yahya and Yahya (2023), the PSO technology was employed to optimise and enhance the voltage at the DC bus of the PVS. This technique provided acceptable efficacy, but in turn, we observed in the results a clear deformation and turbulence on the bus DC. In order to fill the defects and gaps in P&O technology, researchers developed the MPPT technology based on artificial intelligence (AI). In Arpaci et al. (2019) and Abdelaziz et al. (2021), the authors proposed the MPPT technology based on the fuzzy logic controller (FLC) of the PVS. It was compared with the P&O algorithm, where the results of this work were resolved There is a clear superiority of FLC over P&O in terms of efficiency and performance. In Bouarroudj et al. (2021), a methodology was introduced to design an FLC based on the PSO algorithm in order to improve the performance of the PVS. This work helped provide good performance in terms of oscillations and disorders. However, this improvement reduced the system's payoff. The effectiveness ratio in this work was 96.15. In previous literature, the authors presented studies of wind and PVSs independently. Khan and Mathew (2019) and Paragond et al. (2014) presented studies in which the PVS was integrated with the wind system to form a hybrid system. Paragond et al. (2014) presented the study of the hybrid system. The P&O algorithm was used for the PV and wind power systems. Khan and Mathew. (2019) also presented a study of a hybrid system consisting of a WECS and a PVS. The FLC was relied upon to raise and improve the system's performance. However, these studies were undertaken the absence of a storage system, which is an important element of self-based hybrid systems, due to the indiscriminate nature of wind speed and solar radiation. Other authors have therefore introduced renewable energy-based systems supported by the storage system. The authors' work included (Doshi and Harish, 2021; Hassan et al., 2016) PVS and WECS-based hybrid systems that were supported by a storage battery. A bidirectional converter was employed to regulate the charging and discharging of the battery. A proportional integral (PI) controller is in charge of this converter. However, it is known that the disadvantage of the PI controller is disturbance and deformation upon a sudden change in one of the variables. In addition to the results shown in these studies, we observe a noticeable distortion on the DC bus. In Das and Akella (2018), the FLC was relied upon to improve the converter performance. The results were better compared to the PI controller results. Yet, the results show little deviation on the DC bus when the wind speed or solar radiation changes. According to the available literature, many authors have utilised the P&O algorithm for its convenient and uncomplicated installation in their work. Additionally, some of them utilised the FLC technique to optimise the efficiency of the PVS and WECS systems, but separately.

The study we are presenting aims to fill the previous gaps and enhance the efficiency of the hybrid system. This study aspires for the following contributions:

- Enhancing the efficiency and performance of the PVS using the FLC-MPPT technique.
- Enhancing the efficiency and wind power conversion system using the FLC-MPPT technique.
- Improving the power storage system performance based on the PI-adaptive neuro fuzzy inference system (ANFIS) controller.
- Increasing the efficiency of energy production while preserving battery longevity.
- Designing a hybrid system with optimal efficiency.

The remaining parts of this paper are indexed as follows: Section 2 presents a description of the proposed hybrid system. Section 3 presents the modelling of the components of the hybrid system. Section 4 presents the method for improving the efficiency of the system. Simulation results are presented in Section 5. Finally, this work is concluded in Section 6.

2. System Description

The proposed hybrid system consists of a compact PVS with a reinforcement DC/DC converter and a WECS that consists of a wind turbine associated with the PMSG, which is then connected to the alternating current (AC)/DC rectifier. The latter is connected to the DC/DC converter. We implement the FLC-based (MPPT) technique in each of the systems (PVS, WECS), and both these systems are supported by a lithium-ion-type storage battery connected to a DC/DC bidirectional converter. ANFIS-PI is used for the intelligent control of the battery's bidirectional converter. All the models mentioned are connected in parallel with the DC-link. The latter is connected to a resistant load, as shown in Figure 1. PVS and WECS serve as the main sources of electricity generation. While the battery is used to store surplus power when maximum power is produced, the batteries support the system in case of an energy deficit. AI technologies such as FLC and ANFIS have been relied upon. These technologies give better results compared to traditional technologies such as P&O algorithm and PI controllers. It reduces oscillations and deviations at the maximum point of energy. The performance of the storage system has also been improved.

3. Modelling Hybrid System Component

3.1. PV panel

A PV cell is an electronic device that converts light energy into electrical power by harnessing the PV effect of semiconducting materials. A PV cell is an electrical device that demonstrates changes in current, voltage and resistance when exposed to light Chu and Chen (2009). The solar cell's equivalent circuit is illustrated in Figure 2. The equations below represent the numerical changes in the equivalent PV cell circuit (Bengourina et al., 2018; Mahmmoud et al., 2023).

$$Ic = Iph - Is\left((e^{\frac{q(Vc - Ic\times Rs)}{n*K*Tck}} - 1) \right) - \frac{Vc + Ic \times Rs}{R_{SH}} \tag{1}$$

$$Vco = \frac{n \times K \times Tck}{q}\, ln\left(\frac{Iph}{Is}\right) \tag{2}$$

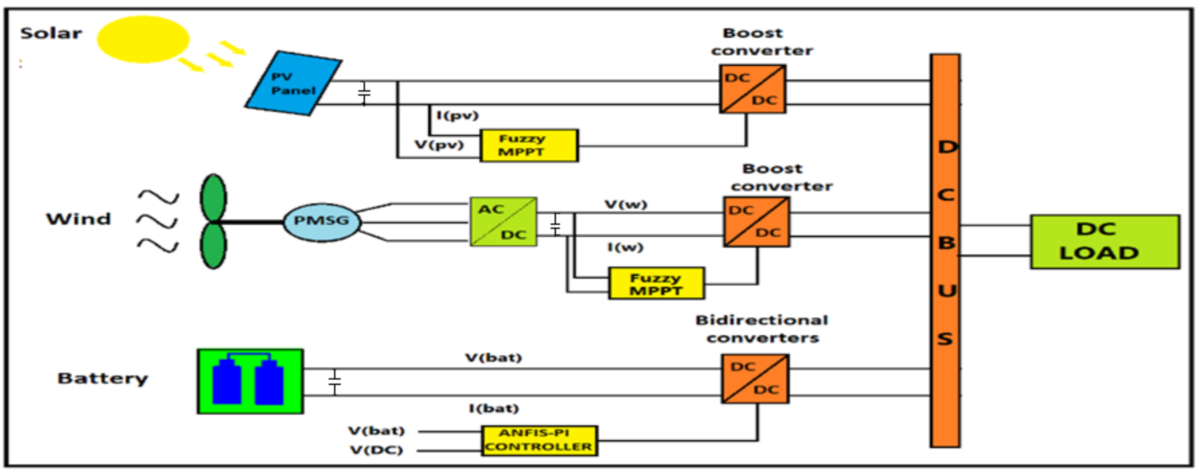

Figure 1. Block diagram of the proposed hybrid system. AC, alternating current; ANFIS, adaptive neuro fuzzy inference system; DC, direct current; MPPT, maximum power point tracking; PI, proportional integral; PMSG, permanent magnet synchronous generator; PV, photovoltaic.

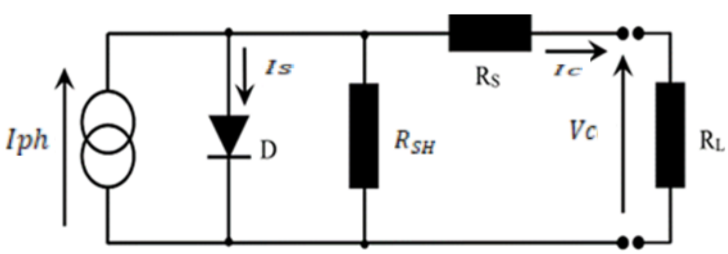

Figure 2. Equivalent circuit of the solar cell.

where *Ic* represents the current flowing through a cell, measured in ampere (A). *Is* is the diode saturation current. *Iph* is the amount of electric current generated by the cell, measured in ampere (A). *Vc* represents the voltage of a cell, measured in volt (V). *Vco* is the open circuit voltage (*V*). *Rs* represents the value of the series resistance in ohm (Ω). R_{SH} is the resistance of the shunt, measured in ohm (Ω). The value of *q* is 1.6×10^{-19} Coulombs (*C*). The value of *K* is 1.38×10^{-23} J/K. The variable *n* represents the nonidealistic constant of a diode. *Tck* is the temperature of the cell, measured in Kelvin (K).

3.2. WECS

WECS is a power-generation system that exploits wind energy. The system comprises a wind turbine, an electric generator and power electronic converters. The turbine is rotated by the wind, which drives the generator to transform mechanical energy into electrical energy. PMSG is a widely preferred generator option because of its cost-effectiveness in terms of maintenance and user-friendly nature. The calibre of the generated power is enhanced by employing power electronic converters where the AC/DC converter transforms AC into DC, whereas the DC/DC converter supplies consistent and dependable energy to the load.

Figure 3 illustrates the system that has been suggested. The subsequent equation delineates the expression of mechanical power generated by wind turbines (Benkada et al., 2018).

$$P_w = \frac{1}{2}\pi\rho R^2 c_P(\beta \cdot \lambda)v^3 \tag{3}$$

So that, P_w is the mechanical power in watt. *ρ* presents the air density in kilograms per cubic meter. *R* represents the radius of the wind turbine, measured in meter. The power coefficient c_P is a measure that quantifies the correlation between the mechanical power produced at the turbine shaft and the power available in the wind. *π* is a mathematical constant with a value of 3.14. *λ* represents the tip-speed ratio. *β* denotes the pitch angle. The wind speed to which the turbine is exposed is denoted by (*V*) and is measured in meter per second.

3.3. Battery system storage

To enhance the energy management and maintain a steady electricity supply from wind and solar sources to the electrical grid, it is recommended to incorporate a battery unit into the suggested hybrid system. This device functions as an ESS during periods of surplus production and serves as a supplementary energy source when other renewable energy sources are insufficient to fulfil the energy demand. The unit comprises a battery that is connected to the DC bus of the hybrid system using a bidirectional converter (see Figure 4).

To maintain the storage unit's optimal performance, it is imperative to consistently control the voltage, which is contingent upon the battery's state of charge (SOC). The SOC is defined by the battery's maximum capacity (C_{max}) (Toual et al., 2020), the current flowing during both charging and discharging (i_{bat}) and the duration of the operation. The relationship is represented by the Eq. (4):

$$SOC(t + \Delta_t) = SOC(t) + i_{\text{bat}}.\Delta_t / c_{\max} \tag{4}$$

(a) (b)

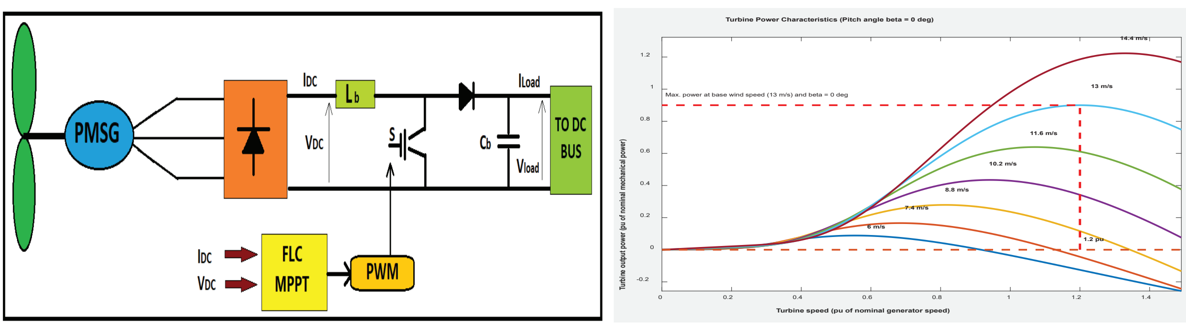

Figure 3. (a) Illustration depicting the structural design of a WECS and (b) Wind turbine power characteristics. DC, direct current; FLC, fuzzy logic controller; MPPT, maximum power point tracking; PMSG, permanent magnet synchronous generator; WECS, wind energy conversion system.

4. Improving the Performance of the System

4.1. Fuzzy logic (FL) MPPT

The MPPT technique enhances and elevates the efficiency and output of both the solar system and the wind power system. The most widely adopted technologies are the P&O and the INS. However, these methods have become conventional due to their drawbacks, particularly in the context of scientific advancements. Several novel MPPT technologies utilising AI, such as FLC and ANFIS, have been developed. In this work, the study employed the FLC-based MPPT technique to optimise energy extraction from the hybrid PV wind system and transfer that energy to the load. The DC/DC converter transfers the maximum power from the units to the loads. To design the FLC, we must identify the main control variables and also the groups describing the values of each linguistic variable. In our work, input variables were considered to be composite conductance $G(K)$ and changes in composite conductance $\Delta G(K)$. The signals are computed and transformed into language variables. As for the output of FLC, it is the change in the operational cycle $D(K)$. Figure 5 shows the proposed MPPT chart.

The suggested FLC-based MPPT method converts variables, such as error and change in error, into membership values using a triangle membership function. The range of the input variables is set to (−5, 5). Membership functions are defined for seven fuzzy sets, which are represented by linguistic variables such as NB, NM, NS, ZE, PS, PM and PB. Hence, N represents negative values. P represents positive values. Figures 6-8 represents parameters of fuzzy logic controller.

4.2. Battery ANFIS controller

The present paper proposes the utilisation of ANFIS to control the battery converter. ANFIS is a form of AI that combines both artificial neural networks (ANN) and FL. The synthetic neural network seeks to replicate human brain

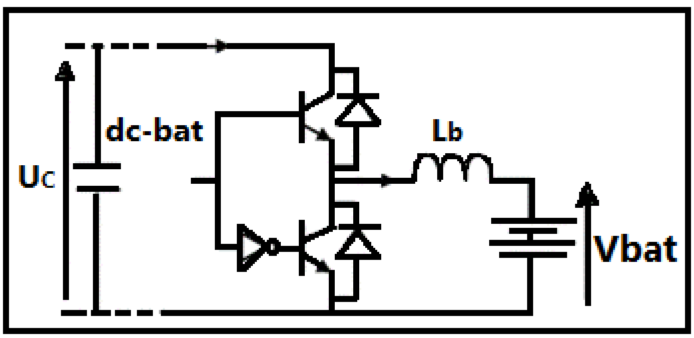

Figure 4. Scheme of the storage system. DC, direct current.

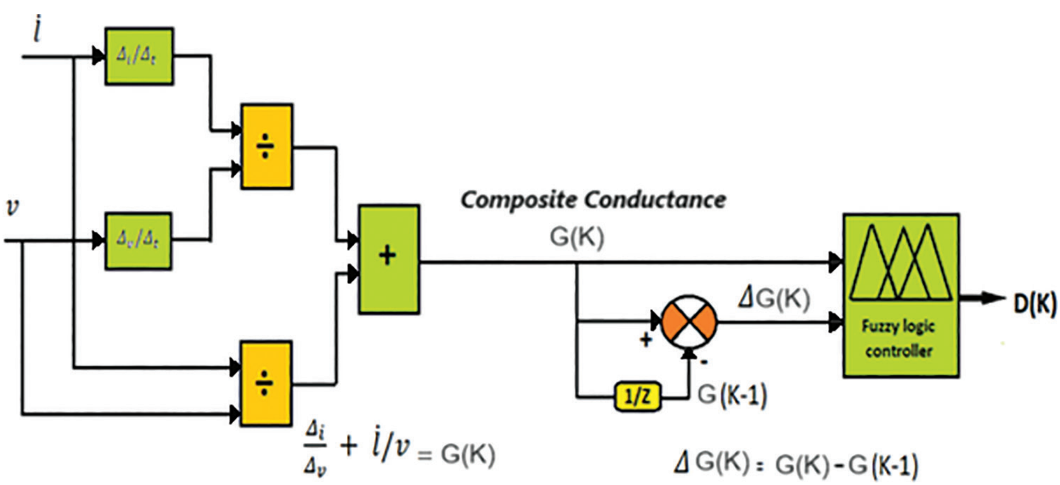

Figure 5. The FLC-MPPT technique scheme proposed. FLC, fuzzy logic controller; MPPT, maximum power point tracking.

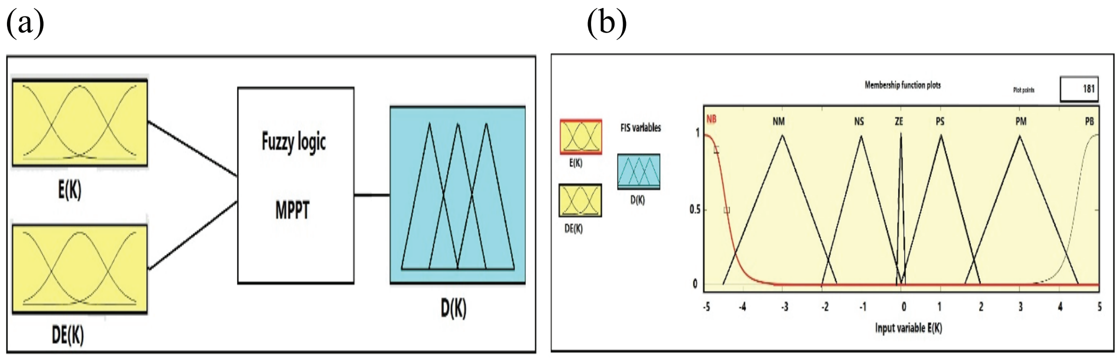

Figure 6. (a) FL designer and (b) The input of FLC (Error, E(K)). FL, fuzzy logic; FLC, fuzzy logic controller; MPPT, maximum power point tracking.

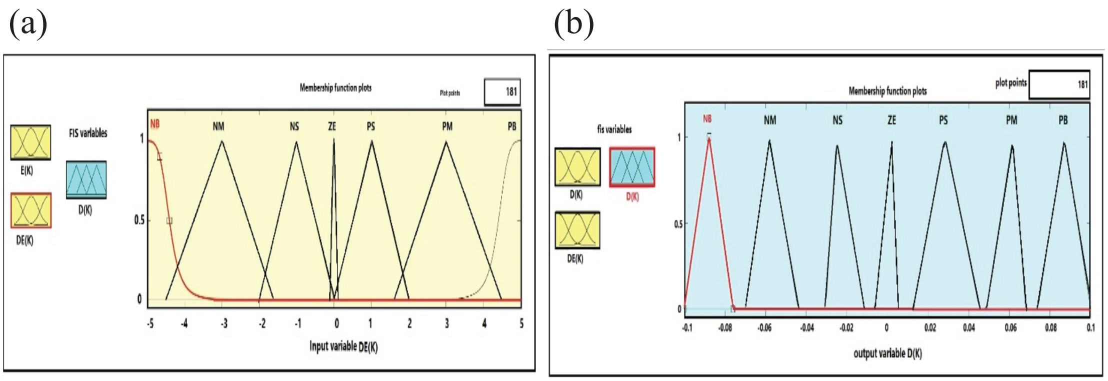

Figure 7. (a)The input of FLC (Change of error, DE(K)) and (b) The output of FLC (Duty, D(K)). FLC, fuzzy logic controller.

DE(K) \ E(K)	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	ZE	PM
NM	NB	NB	NB	NM	NS	PS	PM
NS	NB	NB	NM	NS	ZE	PM	PM
ZE	NB	NM	NS	ZE	PS	PB	PB
PS	NM	NS	ZE	PS	PB	PB	PB
PM	NS	ZE	PS	PM	PB	ZE	PB
PB	ZE	PS	PM	PB	NS	PS	PB

Figure 8. The rule table for FLC. FLC, fuzzy logic controller.

characteristics and includes an array of artificial neurons. An adaptive system is a multi-nodal system in which each node or neuron contributes to the processing of input signals. Figure 9 displays the ANFIS structure. Fixed nodes are depicted as circles, while the adaptive node is depicted as a square.

The battery energy system is controlled using a buck-boost bidirectional converter. This is done using the proposed PI-ANFIS smart controller. In this work, we trained the proposed console using a set of data obtained from the PI controller. Figure 10 illustrates the suggested control loop. We can see from the shape that the battery control depends on the comparison between the DC bus voltage and the reference voltage. This comparison allows us to give an IBat-ref reference stream. Through this current, we can get the PWM signal. Through this signal, we can control the bidirectional converter and get the required power in case of charging or discharge.

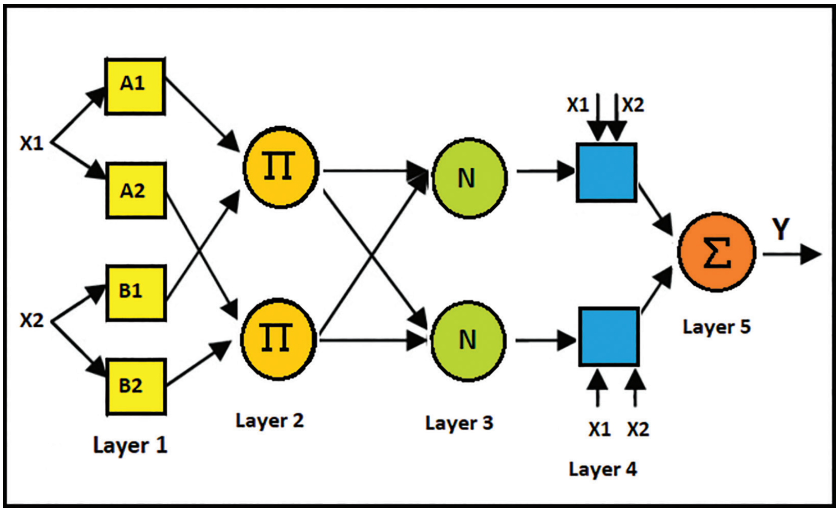

Figure 9. Architecture of an ANFIS. ANFIS, adaptive neuro fuzzy inference system.

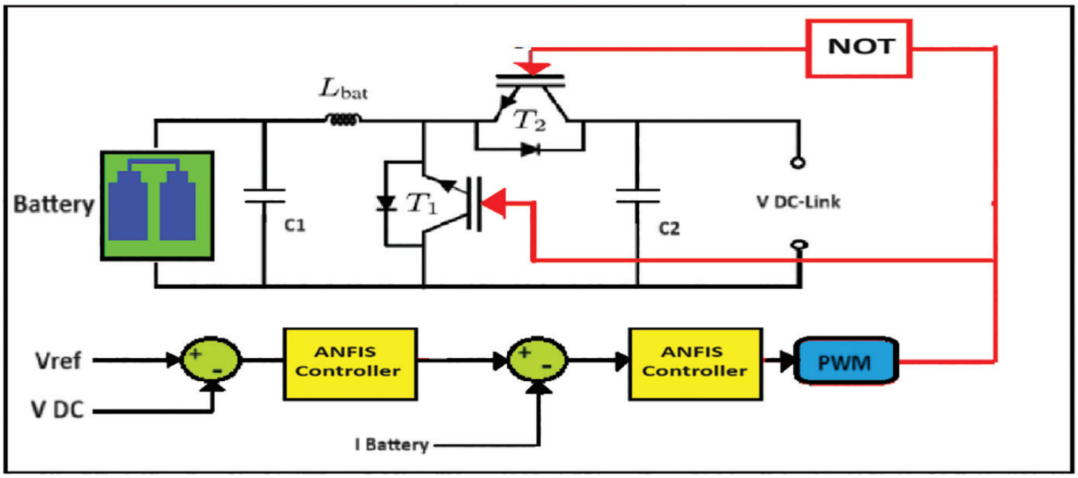

Figure 10. Proposed controller-based ANFIS for bidirectional converter. ANFIS, adaptive neuro fuzzy inference system; DC, direct current.

5. Simulation and Result

5.1. Improving the effectiveness of the hybrid system

The present paper aims to study and analyse the functioning of the proposed hybrid system and verify its effectiveness and efficiency. Several simulations were performed using the MATLAB/SIMULINK software. The general description of the system appears in Figure 1. The DC-Link voltage is regulated at 535 V, while the DC load has a power rating between 11 kW and 16 kW. We used a 12-kW wind turbine simulated using a real wind speed model, as illustrated in Figure 11(a). We used solar panels with 10 kW of generating power. They were simulated in different climatic conditions with solar radiation ranging from 0.5 kW/m² to 1 kW/m², while the temperature was considered constant at 25°C. Figure 11(b) shows the value of solar radiation applied to this work. The storage system utilised an 8-kWh lithium-ion battery. The voltage value is 320 V, and the current value is 30 A. The proposed system must be effective and robust under all circumstances. This is why the proposed FLC technology has been compared with the P&O algorithm. The proposed ANFIS controller has been compared with the PI controller. Taking into account the following performance criteria: rapid response and tracking, oscillation amplitude and the effectiveness of the system.

The criteria used to select the loading profiles for Wind and PV are the following:

A realistic wind speed that facilitates the comparison between the studied techniques (FLC MPPT/P&O MPPT) and the testing of the WECS efficiency in various values of wind speed (Sakouchi et al., 2023).

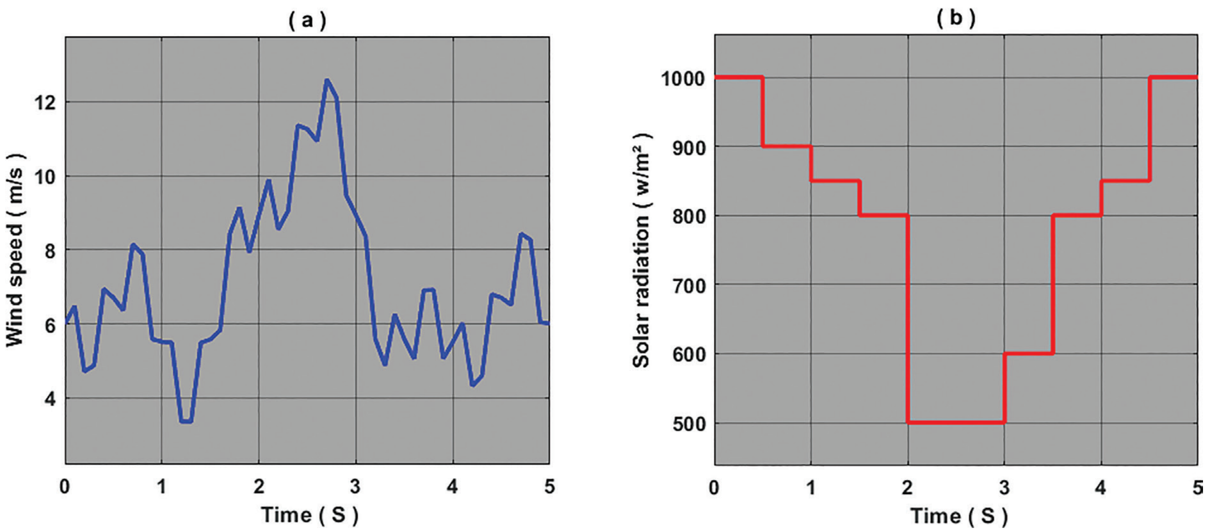

Figure 11. Proposed weather conditions (a) wind speed and (b) solar irradiation.

Table 1. Specifications for the power electronic converters.

Parameters	Boost converter	Bidirectional converter
Capacitor	1.850 mF	1.27 mF
Inductor	1.123 mH	0.61 mH
Switching frequency	10 kHz	10 kHz

Various solar radiation values were used to compare between the two studied techniques (FLC MPPT/P&O MPPT) and examine the efficiency of the PVS. Table 1 below shows Specifications for the power electronic converters.

Figure 12 shows the results of the WECS simulator representing FLC vs P&O power output.

Upon examining the chart, we can see that the P&Q exhibits lower efficacy compared to the FLC, where we can observe in the second 0.75, the wind power associated with the P&Q MPPT is equal to 3,000 W at a wind speed of 8 m/s, while the one associated with the FLC MPPT is equal to 4,000 W under the same conditions. Furthermore, the FLC's ability to track the highest power point surpasses that of the P&Q. This can be seen in the second 2.73 at a wind speed of 12 m/s. The wind power recorded for FLC MPPT is 12,400 W, whilst the value in case of the P&O MPPT is equal to 11,900 W. We can also see that the FLC technique can track the reference wind power in various wind speed scenarios. As for oscillations, we can observe that the P&O algorithm has clear oscillations and this is due to the mechanical energy stored in the wind turbines at the moment of inertia. While the FLC technique has minimal value, this is due to the good response and proper tracking of the maximum power point.

Figure 13 shows the PVS simulation results performed at 25° and different values of solar radiation. This work was carried out with two different techniques: FLC and P&O. The graph shows that the effectiveness of the FLC MPPT surpasses that of the P&O MPPT, with a power output value of 9,930 watts under the greatest sunlight of 1,000 W/m^2. The P&O technology output value was 9,700 (W), the same value as solar radiation. Moreover, apart from the poor effectiveness of the P&O technique, we note that it also has another drawback, which is that the oscillation occurs at the moment of highest energy. FLC's tracking exceeds P&O's tracking. This proves the power of the proposed technology, based on AI.

To more accurately verify the effectiveness of the PVS and WECS systems, they were combined to form a hybrid system. A storage battery has also been employed to improve the performance and management of the hybrid system to store surplus power or unload power according to the system's needs. Figure 14 shows the energy produced from the hybrid system under different conditions of wind speed and solar radiation with two different technologies. We note that the FLC outperforms the P&O in terms of effectiveness, oscillation and tracking.

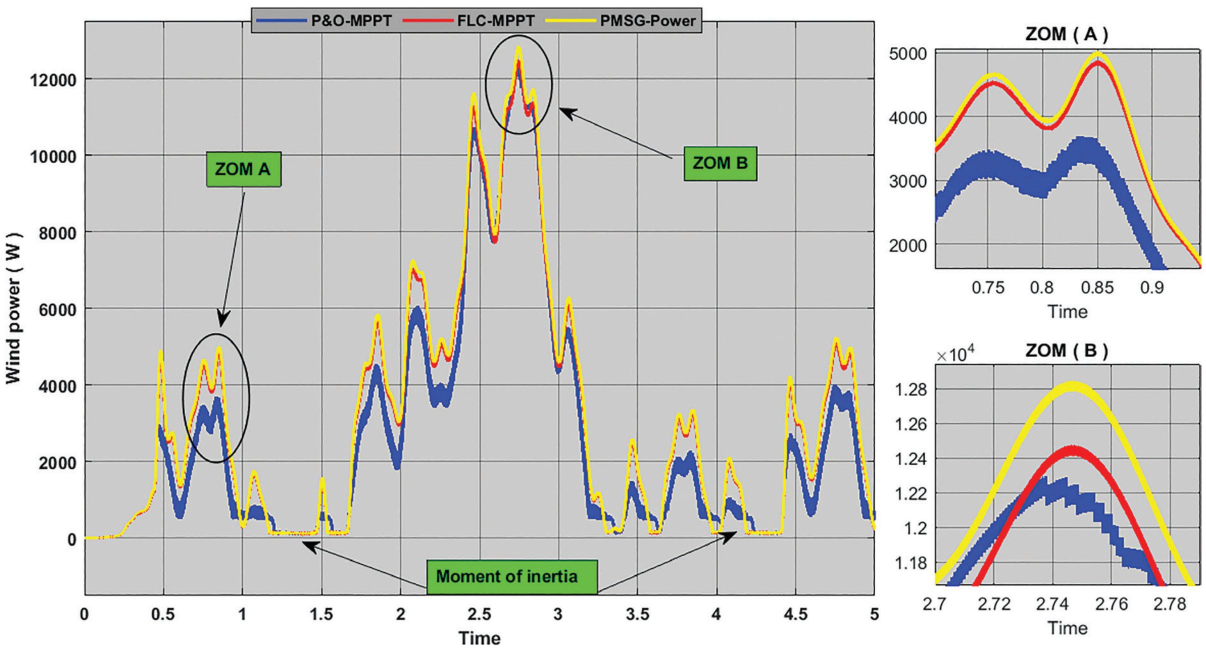

Figure 12. Comparison of the wind power output utilising the FLC-MPPT and the P&O-MPPT. FLC, fuzzy logic controller; MPPT, maximum power point tracking; P&O, Perturb and Observe; PMSG, permanent magnet synchronous generator.

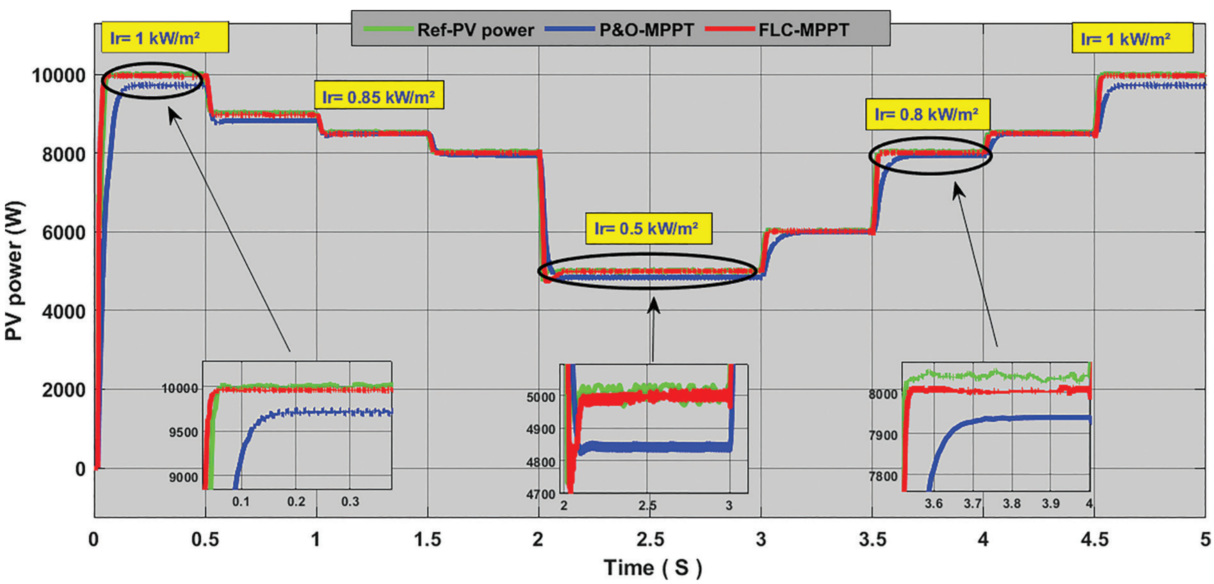

Figure 13. Comparison of PV power output utilising the FLC-MPPT and the P&O-MPPT. FLC, fuzzy logic controller; MPPT, maximum power point tracking; P&O, Perturb and Observe; PV, photovoltaic.

Figure 15 shows the battery power of the proposed system. The management of this system depends on storing surplus energy in the event that the energy production is greater than the load value and discharging the energy in the case that the energy production is less than the load needs. We can see from the graph that the FLC technology enables the storage of a larger amount of energy compared to the P&O algorithm. This is due to the effectiveness of the FLC technology, which allows for a greater energy production than the P&O algorithm. Table 2 presents a comprehensive comparison of the performance between the suggested technique and the classical technique, providing more detailed information.

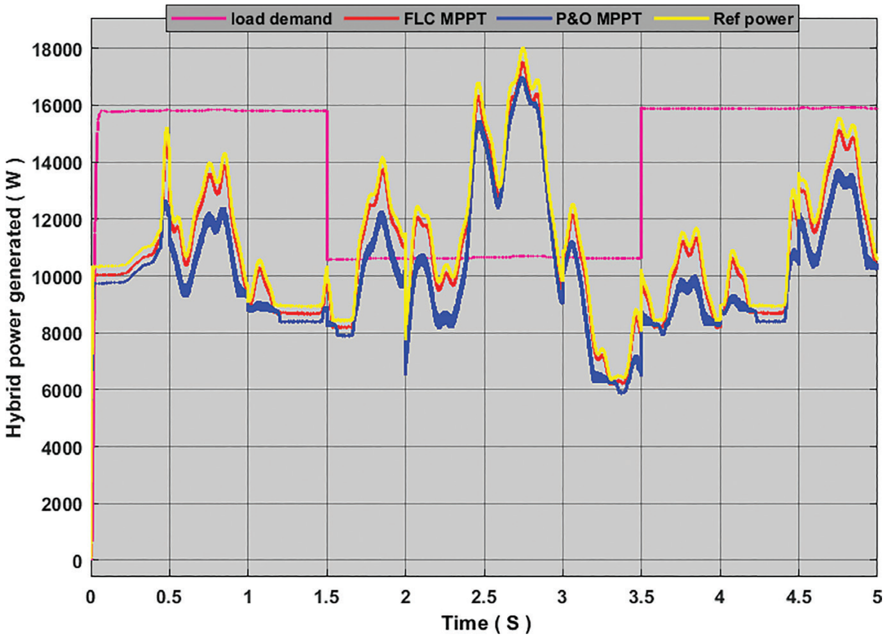

Figure 14. Comparison of hybrid system power output utilising the FLC-MPPT and the P&O-MPPT. FLC, fuzzy logic controller; MPPT, maximum power point tracking; P&O, Perturb and Observe.

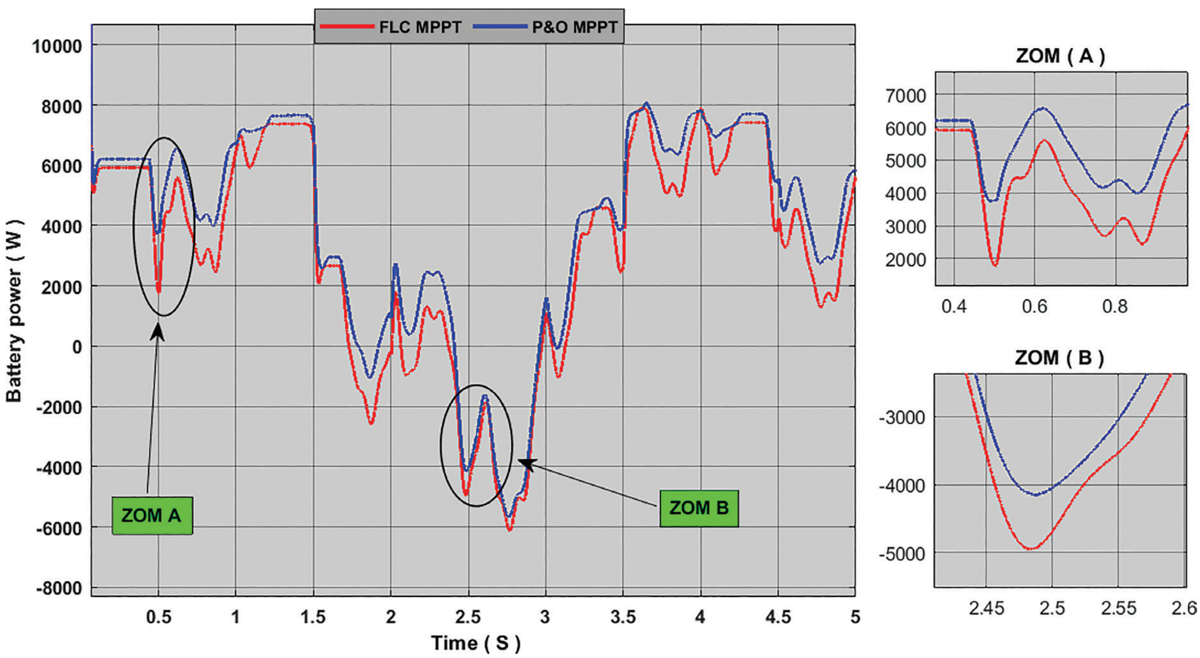

Figure 15. Comparison of battery power utilising FLC-MPPT and P&O-MPPT. FLC, fuzzy logic controller; MPPT, maximum power point tracking; P&O, Perturb and Observe.

5.2. The ANFIS controller for the bidirectional converter

A storage system is essential for maintaining consistent and dependable power quality in hybrid systems depending on renewable energy sources, which are known for their unpredictable nature. This work introduces an intelligent controller utilising ANFIS to efficiently regulate the bidirectional converter of the storage system. The objective of the proposed controller is to maintain voltage stability at the specified reference value of 535 volts and minimise

Table 2. Comprehensive comparison of the effectiveness between the FLC-MPPT and the P&Q-MPPT.

System	Input power (kW)	Output power (kW) with P&O-MPPT	Output power (kW) with FLC-MPPT	Effectiveness (%)	
				P&O	FLC
PV	10	9.65	9.97	96.5	99.70
	8.1	7.80	8.05	96.3	99.40
	5.05	4.85	5.00	96.03	99.10
Wind	12.5	11.9	12.4	95.20	99.20
	5.2	4.50	5.00	88.30	96.10
	3	2.20	2.80	73.00	93.33
Hybrid	18.0	16.25	17.10	90.25	94.65
	14	12.50	13.5	91.80	96.06
	12	11.1	11.5	91.50	95.50
Battery	18	−5.40	−6.10	92.00	95.05
	14	4.00	2.80	89.00	96.06
	12	5.8	4.20	91.20	96.00

FLC, fuzzy logic controller; MPPT, maximum power point tracking; P&O, Perturb and Observe; PV, photovoltaic.

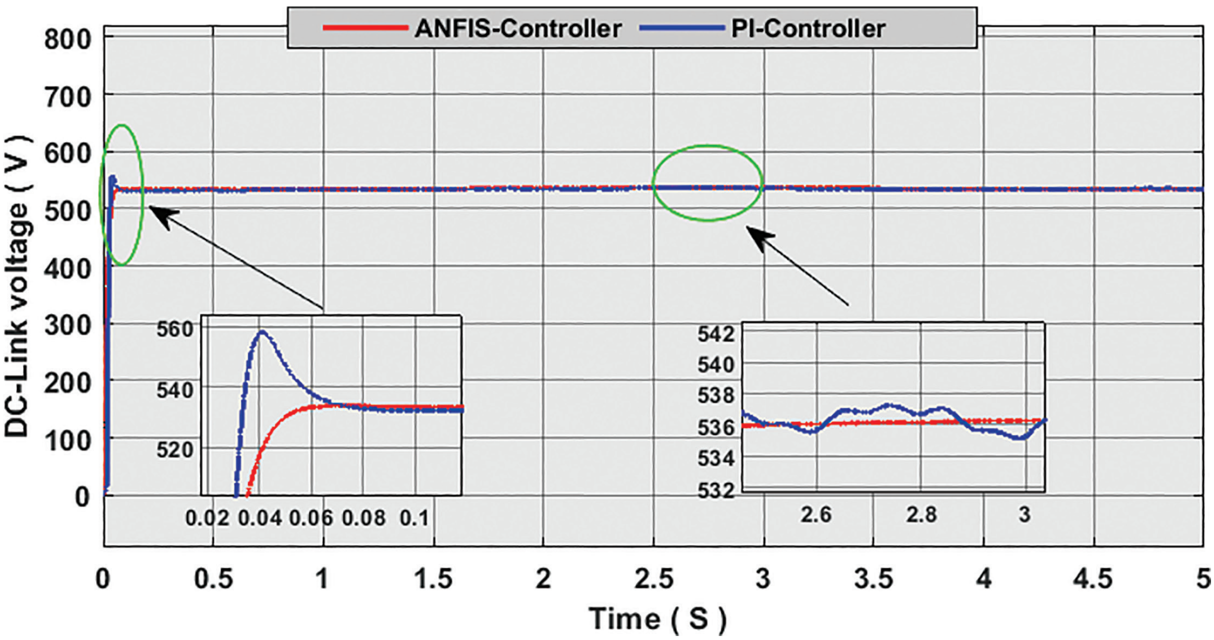

Figure 16. DC-Link voltage, Comparison between PI and ANFIS controllers. ANFIS, adaptive neuro fuzzy inference system; DC, direct current; PI, proportional integral.

oscillations in current on the DC bus. Figures 16 and 17 demonstrate that the proposed controller maintains a consistent voltage at the DC bus regardless of weather conditions. Conversely, the PI-based controller exhibited distortions and deviations when faced with abrupt changes. Additionally, it is evident from the diagram that the suggested method has effectively decreased the magnitude of fluctuations in the current passing through the load.

Figures 16 and 17 illustrate the results of the DC-LINCK simulation voltage and the current obtained by the two techniques, PI-controller and ANFIS-controller. The ANFIS-controller is the suggested technique while the PI-controller is a formerly studied technique. This was done in order to test the performance of our suggested technique compared with the PI-controller technique. Table 3 helps one to obtain a better understanding of the dynamic difference between these two techniques by giving more details.

Figure 18 shows the load power on the DC bus. The simulation results show that the proposed controller provided sound and stable power quality that was free of oscillations and deviations in all weather changes occurring throughout the simulation period. By comparison, the PI-based controller showed some deviations and oscillations. This exemplifies the effectiveness of the proposed technique in ensuring high-quality energy.

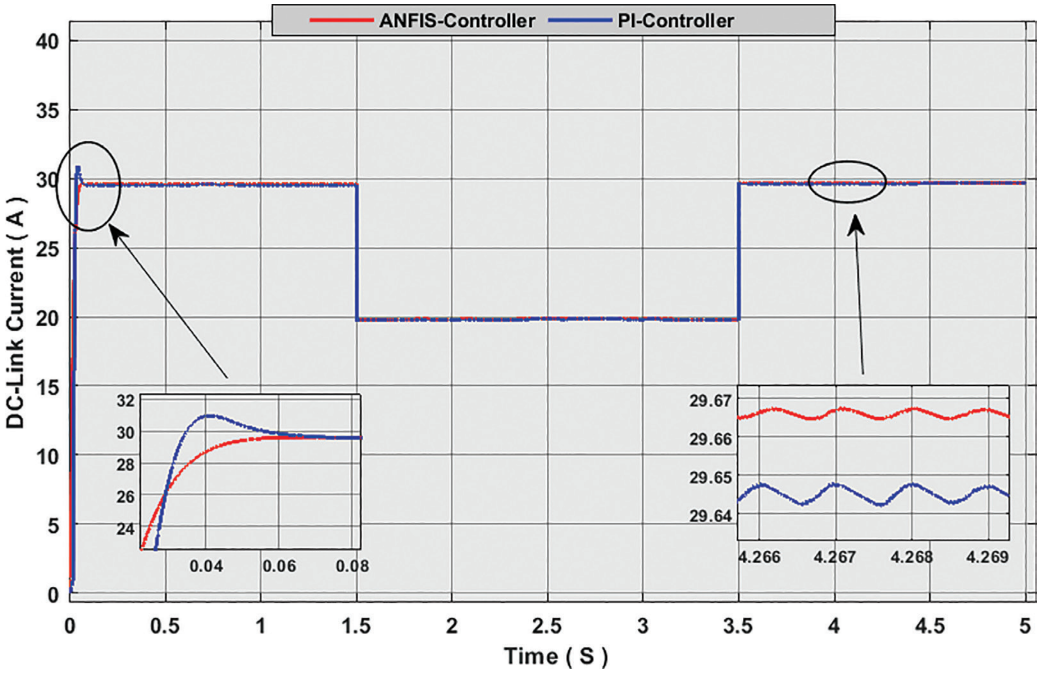

Figure 17. DC-Link current, Comparison between PI and ANFIS controllers. ANFIS, adaptive neuro fuzzy inference system; DC, direct current; PI, proportional integral.

Table 3. Comprehensive comparison of the dynamics between the ANFIS-controller and the PI-controller.

Specification	DC-link voltage		DC-link current	
	PI	ANFIS	PI	ANFIS
Overshoot	4.86%	0.05%	4.49%	0.05%
Setting time	0.08 (S)	0.05 (S)	0.08 (S)	0.05 (S)
Peak time	0.07 (S)	0.05 (S)	0.07 (S)	0.05 (S)
Oscillation	Medium	Low	Medium	Low

ANFIS, adaptive neuro fuzzy inference system; DC, direct current; PI, proportional integral.

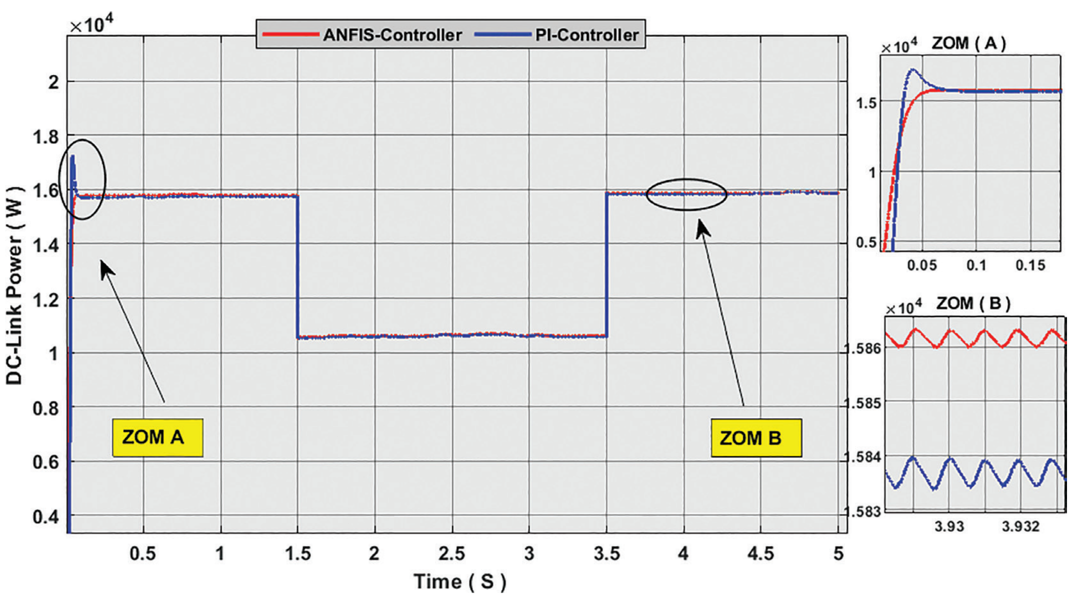

Figure 18. DC-Link power, comparison between the PI and ANFIS controllers. ANFIS, adaptive neuro fuzzy inference system; DC, direct current; PI, proportional integral.

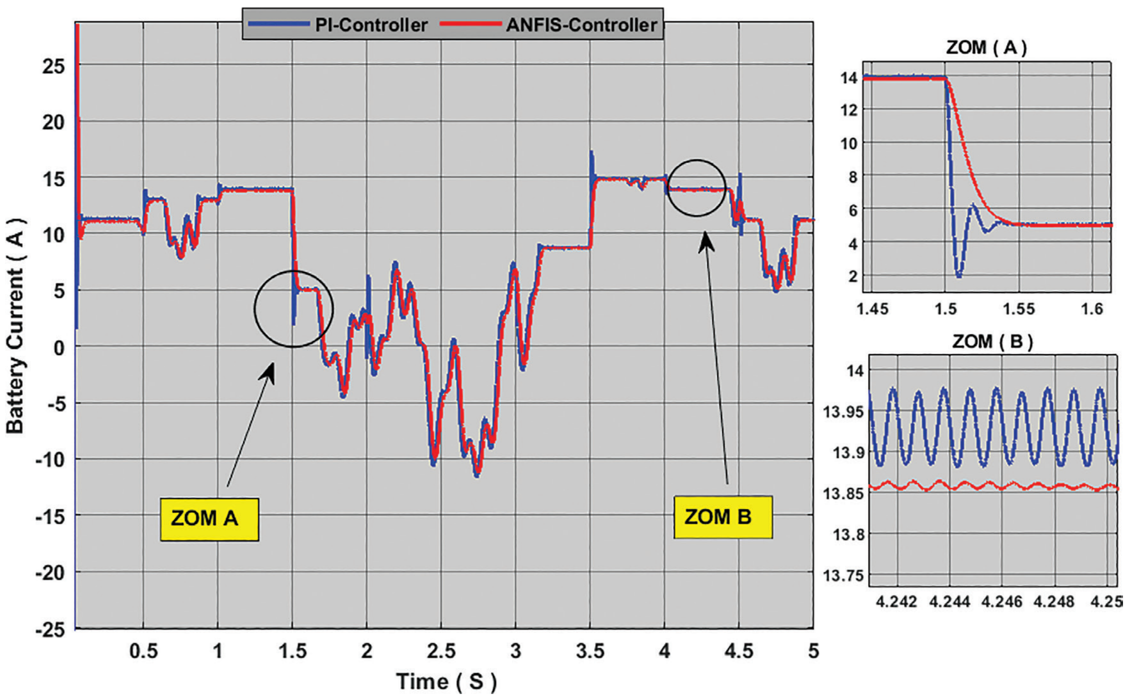

Figure 19. Battery current comparison between the PI and ANFIS controllers. ANFIS, adaptive neuro fuzzy inference system; PI, proportional integral.

Table 4. Parameters of the control system.

PI controller		ANFIS controller	
Ki	0.1	Epochs	100
Kp	0.01	Number of MFs	50
–	–	MF type	Trimf
–	–	Optim method	Hybrid

ANFIS, adaptive neuro fuzzy inference system; PI, proportional integral.

Table 5. Parameters of the hybrid system component.

PV 10 kW			PMSG 12 kW		
Parameters	Symbol	Value	Parameters	Symbol	Value
Maximum power	W	250.92	Stator resistance	Rs (Ohm)	0.5
Open circuit voltage	Voc (V)	37.4	Armature inductance	L (H)	0.000975
Short-circuit current	Isc (A)	8.7	Torque constant	Kt	60.7
Voltage at maximum power point	Vmp (V)	30.6	Pole pairs	P	4
Current at maximum power point	Imp (A)	8.2	Viscous damping	F N.m/rpm	4.5
Parallel strings	Module	4	Inertia	J (kg/m^2)	50
Series per string	Module	10	Flux linkage	€ (Weber)	0.433

PMSG, permanent magnet synchronous generator; PV, photovoltaic.

Figure 19 shows a comparison between the PI controller and the ANFIS controller for battery current. We notice from the diagram that the proposed controller allows charging the battery with excellent current quality, while the PI controller shows some oscillations in the battery current. From the simulation results, we can say that the proposed technology allows for an increase in battery life, due to the good quality of power with which it is charged.

Tables 4 and 5 shows parameters of control system and the hybrid system component respectively.

6. Conclusion

This study focuses on improving the efficiency of the hybrid system that relies on renewable sources through modelling and analysis. The system comprises wind energy system, a solar energy system and a storage battery system. In order to enhance and fortify the performance of this hybrid system, we rely heavily upon AI. The FLC-MPPT is employed to regulate the DC/DC converter in both PVS and WECS, with the aim of accurately following the maximum power point. A controller based on the ANFIS is suggested for regulating the bidirectional converter of the storage system. This study's simulation results show that the FLC-MPPT works better than the P&O in PVSs and WECSs in terms of both efficiency and power quality. The ANFIS controller demonstrates superior performance compared to the PI controller in terms of stabilising the voltage on the DC bus and mitigating current variations at both the DC bus and the battery current. The proposed system demonstrates superior performance in terms of effectiveness and reliability in energy conservation under all conditions, exceeding previously established systems documented in the literature. The proposed system is suitable for use in remote locations and isolated from the electrical network, owing to its high efficiency and reliability.

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