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Enhancing Power Quality in Integrated PV Systems and DFIG Systems through MPPT and Fuzzy logic controller for Grid Systems

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Abstract. This article investigates incorporating solar energy into a grid connected system or process—Photo-Voltaic (PV) and Double Fed Induction Generator (DFIG) systems aimed at improving energy efficiency. Because of its lower efficiency, successfully using the power from solar PV connected to the utility grid is a challenging operation. The hybrid system operation is optimized using a Fuzzy Logic Controller (FLC), which effectively manages the variability and intermittency of renewable sources. The FLC dynamically adjusts parameters to ensure seamless grid integration and power quality enhancements. The study compares the FLC's performance with the Incremental Conductance method, evaluating their ability to manage the hybrid system's components under diverse environmental conditions. Key focus areas include voltage regulation, frequency stability, and harmonic distortion mitigation. A power point tracking controller's primary function is to increase or maximize solar systems' power generation. This proposed method includes a presentation of a fuzzy controller with Maximum power point tracking (MPPT) for a 10 kW-PV grid connected systems, highlighting its advantages over the Incremental Conductance method (Inc-Con). The output results are verified and validated with MATLAB Simulink platform.

1 Introduction

As global demand for renewable energy solutions continues to grow, non-conventional energy sources such as solar photovoltaic and wind power are vital for cleaner, more sustainable energy. The PV panels will convert solar energy in to DC electric energy [1]. However, their integration poses a challenge due to their instability, inconsistency and less efficiency [2]. Researchers developed a combination of an MPPT controller and a photovoltaic energy converter. Solar photovoltaic energy is environmentally friendly, requires less maintenance [3, 4], and has 15-25% efficiency. Large wind turbines using DFIG with back-to-back converters can vary their operating speed with only 20-30% of the electricity generated through the converters. Always check for attacks on DFIG systems. To improve power efficiency and connect the solar-wind hybrid power system to the grid, this work presents a fuzzy logic controller for the DFIG control system using d-q separation rotor current vector control. The controller constantly adjusts the system settings in real-time to optimize the system's performance, ensuring a steady and harmonic connection with the grid. The research also highlights the importance of continuing to use multiple energy sources simultaneously, including wind at night, to meet consumer demand. The ultimate goal is to increase the energy efficiency of hybrid systems by taking advantage of photovoltaic and wind energy features.

Control of the variable speed of generator induction (DFIG) by PWM converter on the rotor side is proposed using fuzzy logic-based rotor flux-oriented vector control to control rotor current. A fuzzy logic controller and PI controller are used to control the rotor current to overcome all disturbances. Simulations were created in MATLAB Simulink. [5]. Simulating the doubly fed asynchronous generator (DFIG), the main wind turbine used for wind power generation, and its role in managing active and reactive power in the network is presented. Uses MATLAB Simulink for design and simulation. [6].Network control has been improved, especially when photovoltaic energy enters the low-voltage distribution network. It uses D-STATCOM in FACTS devices to improve power control and power stability. Use MATLAB SIMULINK to assess the effectiveness of your system. Research and evaluation of standards in various fields of work. [7].

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Put forth for use in wind power applications, the neuro-fuzzy control for doubly fed induction generator (DFIG) based direct power control is created utilizing the MPPT technique. The controller replaces the original DPC drive with space-vector modulation and active and reactive power controllers. The Neuro-Fuzzy control's performance is compared to the PID controller, showing superior dynamic performance and robustness in MATLAB Simulink [8].The use of doubly fed induction generators (DFIG) in wind turbines to improve energy capture and controllability is described. It uses a 12-bus multiple system with a 400 MW wind farm and uses vector control technology, classical PI controllers, and fuzzy controllers to create reactive and active power control of the stator and grid. [9].

2 System Architecture

In contrast to previous Grid-integrated systems, the suggested system offers PV and Grid-tied generation systems power quality enhancement, voltage regulation, etc. Here, we improved system performance using DFIG wind energy systems with a fuzzy controller. The next parts contain a description of the design and the software implementation. Photovoltaic (PV) power generation is making a comeback in residential applications due to its endless renewable nature and zero carbon emissions. However, inconsistent supply and variable load demand lead to a power mismatch. Energy storage system integration with household generating systems and their connection to the main grid act as buffers to increase micro grid stability and distribute power continuously.

Solar Photovoltaic (PV) technology involves the conversion of sunlight into electricity using semiconductor materials. The fundamental principle behind solar PV is the photovoltaic effect. Certain materials, usually silicon-based, produce an electric current when they come into contact with sunshine. A photovoltaic (PV) system's solar cells, typically comprise a combination of semiconductor materials like crystalline silicon or thin-film, are its core component. These cells, which tend to be polycrystalline and mono-crystalline, are combined to create PV modules, or panels, which often appear on solar farms or roofs. These modules have a minimum 25-year lifetime and are made to survive extreme temperatures. Inverters convert DC power from solar panels to AC for grid or domestic uses. An ideal solar system can be considered as the current location. The current produced is proportional to the solar radiation falling on it. The battery is produced from 0.5V to 1V. Figure 1 shows a schematic diagram of a household network connected to photovoltaic power.

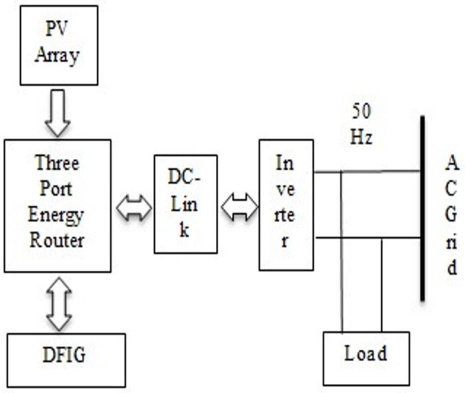


Fig. 1. Structure of a Grid-tied PV and DFIG system General current expression for photo voltaic is

$$I = I_{ph} - I_s * \left[exp\left(V_{pv} + \frac{R_{spv} * I_{pv}}{n * VT}\right) - 1\right] - \left(V_{pv} + R_{spv} * \frac{I_{pv}}{R_{sh}}\right) \text{- (1)}$$

The following table give the parameters of PV and DFIG systems

Table 1. Parameters of PV system

Name of the parameter	**values**
Number of parallel strings	6
Series-connected modules per string	9
Cells per module(Ncell)	50
Open circuit voltage(V_{oc}) in volt	30.8
Short circuit current I_{SC}(Amps)	8.7A
Voltage at maximum power point V_{mp}(volts)	24.5V
Current at maximum power point I_{mp}(amps)	8.16A
Temperature coefficient of V_{oc}(%/deg.c)	-0.33
Temperature coefficient of I_{sc}(%/deg.c)	0.1

Table 2. Parameters of DFIG system

Turbine model	3 blade horizontal axis
Stator phase resistance	$0.8e^{-3}$kg$-m^2$
Air density	P=1.225$\frac{kg}{m^3}$
Rated speed of wind	12m/s
Generator parameter	2MW,DFIG
Generator frequency	50HZ

3 DFIG systems

Now we discuss how we integrate the DFIG-based wind power systems into the grid smoothly. Wind power systems using induction generators that are double fed (DFIG) are essential for the renewable energy industry's sustainable power generation. By using wind energy with MPPT controllers effectively, these systems maximize power production and enable variable speed operation. The combination of an asynchronous generator and a power electronic converter makes them feasible.

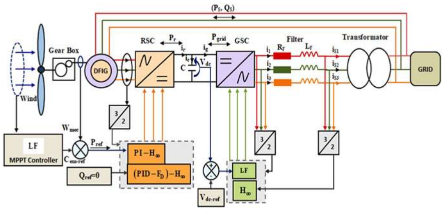


Fig. 2. Integrated DFIG systems with Grid

This investigation of DFIG wind energy systems reveals its critical role in expanding the field of renewable energy by concentrating on their core ideas, benefits, applications, and control mechanisms. One type of electrical generator that is frequently used in wind turbines to convert wind energy into electrical energy is the doubly-fed induction Generator (DFIG). Because it is an asynchronous generator, the rotor's rotating speed is not in sync with the grid's frequency. The stator and the rotor are the two major parts of the DFIG. When three-phase alternating current (AC) is supplied to the stator, the stationary portion of the generator that is directly linked to the grid, a revolving magnetic field is created. The rotor, or rotating part, of the generator is connected to the rotor of a wind turbine and is responsible for converting mechanical energy into electrical energy.

The rotor is linked to the grid via a power electrical device known as the Rotor Side Converter (RSC), which has its own set of windings. Power may pass through the rotor and stator windings simultaneously thanks to the DFIG, which increases efficiency and flexibility in a range of wind situations. To ensure proper voltage and frequency and power factor regulation, the system additionally incorporates a Grid Side Converter (GSC) to govern power flow between the stator and the grid. Because of its grid compatibility and capacity to regulate the generator's power output, the DFIG is a widely used option for wind turbine applications.

The following details are mentioned in Fig.2. A wind turbine's control block is made up of an H-infinity (H∞) controller and a proportional-integral controller (PI), the latter of which is intended to operate steadily and robustly even in the face of disruptions and model inaccuracies. A popular control technique for keeping a system at its intended set point is the PID controller. The feedback element (Fb) provides input so that the PID controller may modify its actions. The voltage of the DC link ($V_{dc\text{-}ref}$) is important for the correct operation of the power converter (RSC and GSC). To guarantee that the DFIG runs at a power factor of unity, the control system controls reactive power. To maximize the generator's performance, the reference value for electromagnetic torque or other control parameters is also utilized.

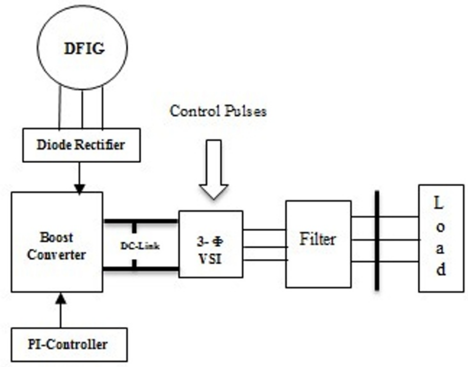


Fig. 3. Modelling of Wind Energy Systems

The mechanical power that an end turbine can produce in a wind turbine with varying speed can be stated as

$P = 0.5 * \rho * A * Cp * Vw^3$ --- (2)

The relation between rotor speed and wind speed can be given by

$\lambda=\omega mR/Vw$ ---(3)

The wind turbine torque on the shaft can be calculated from the power

$Tm=Pm/Wm=0.5\rho\pi R^5(Wm/\lambda)^3Cp(\lambda,\beta)$ ---(4)

Where,

$C(\lambda,\beta)=0.5176((116/\lambda i)-0.4\beta-5)e^{-(21/\lambda i)}+0.0068\lambda$ -----(5)

$\lambda i=[1+(\lambda+0.08\beta)-0.035/(\beta^3+1)]^{-1}$ ----(6)

4 Grid-Integrated PV and DFIG System Setup

Solar photovoltaic (PV) and wind energy systems are key players in this pursuit, offering environmental benefits and low maintenance. However, the inherent intermittency and variability of these sources pose challenges to their seamless integration.

To overcome these problems, researchers have developed complex configurations for MPPT controllers and photovoltaic power converters. Voltage source converters are commonly used for large wind turbines because they allow for back-to-back conversion between the AC mains and rotor windings.

A fuzzy logic controller (FLC) based on d-q decoupled rotor current vector control is designed for the DFIG control system.

To achieve this goal, we developed grid-synchronized fuzzy logic controllers for hybrid photovoltaic and doubly-fed wind energy systems to improve energy efficiency

5 MPPT Techniques Integrated

To maximize power output, renewable energy systems like Photovoltaic (PV) and wind power require MPPT technology. It guarantees that, under a range of environmental circumstances, the system runs at the point where it extracts the most power. The maximum power point (MPP) of solar PV systems is the location on the voltage-current curve where the voltage-current product is at its highest. Real-time operating point adjustments are made via MPPT algorithms for PV systems.

The MPPT techniques used in this system are:
Incremental conductance method
Fuzzy Logic Control

A detailed view of these methods and how the techniques are integrated with PV and DFIG systems is shown below.

5.1 Incremental conductance approach

PV systems commonly use the Incremental Conductance (Inc-Cond) technique as part of the Maximum Power Point Tracking (MPPT) methodology. Its main objective is to ensure that a photovoltaic system operates at its Maximum Power Point (MPP), where power generation is optimized by the product of voltage and current, in a range of environmental conditions. The Inc-Cond approach attempts to dynamically change the operating point of a PV array to monitor the MPP by comparing the instantaneous conductance to a reference conductance.

The incremental conductance (dI/dV) is calculated as the derivative of current concerning voltage.

$(dI/dV) = -I/V(1+(dI/dT)/(dV/dT))$ ---(7).

The incremental conductance is compared with a reference conductance (G ref) from the previous iteration.

$dG = (dI/dV)-Gref$ ---(8)

To calculate the output voltage and current, we use the input voltage and current.

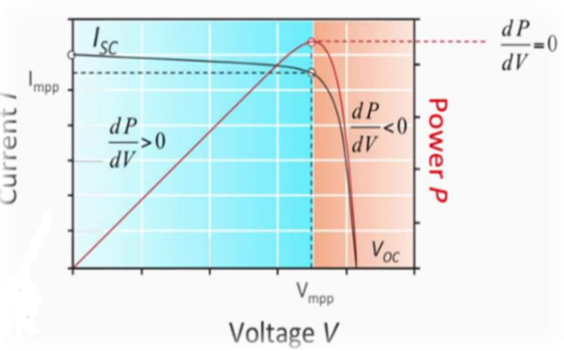


Fig. 4. MPP graph for Inc-Cond method

Fig.4. describes the MPP reaches a point when dP/dV equals zero and the P versus V curve slopes from positive to negative. As voltage moves to the left, current and power rise (positive slope). Conversely, when voltage increases to the right, current reduces quicker, resulting in a loss in power (negative slope).

Zero at MPP
$dP/dV = 0$ ---(a)
Negative at the right of MPP
$dP/dV < 0$ ---(b)
Positive at the left of MPP
$dP/dV > 0$ ---(c)

The procedure begins by measuring the difference in current (dI) and voltage (dV) between two successive sample intervals (k, k+1). If the voltage variation (dV) is zero, the operating point is the minimum power point (MPP) or constant voltage and the duty cycle (d) always remains. If the voltage change is not zero, the flowchart determines the sign of the change. A positive change indicates that the operating point is moving away from the MPP toward a lower voltage, whereas a negative change indicates that the operating point is moving away from the MPP toward a higher voltage.

The procedure subsequently evaluates the ratio between the change in current (dI) and the change in the voltage (dV). If the ratio is positive, the operating point is on the left side of the MPP, which increases voltage and current while decreasing current. If the ratio is negative, the operating point is on the right side of the MPP, which increases voltage while lowering current. The algorithm changes the voltage and current levels after each iteration until they meet the MPP.

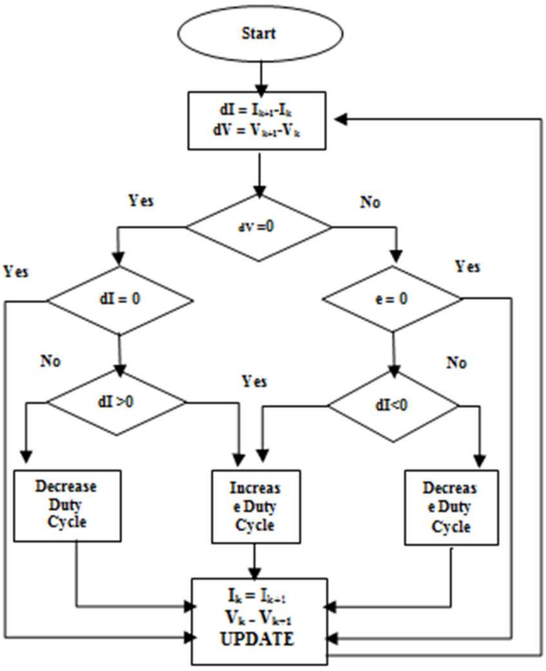


Fig. 5. Inc-Cond algorithm

5.2 Fuzzy Logic Control Approach

Fuzzy logic control has become more popular in recent years due to the ability to control parameters, inaccurate devices, and the lack of a perfect mathematical model. Another important element in its application is the microcontroller. The three levels of fuzzy logic are fuzzification, inference system, and fuzzification. Numeric inputs are blurred or converted into different words depending on the process involved. When a category is assigned by a member function, the value of the variable is controller-dependent. There are several blurs: NI, MI, HI & NV, MV, HV & LD, MD and HD.

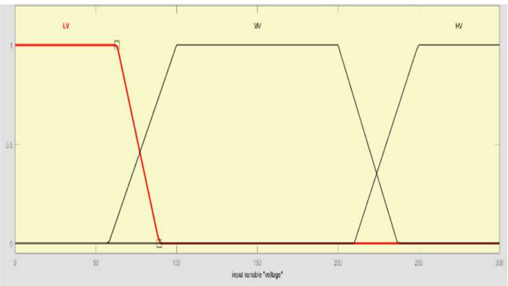


Fig. 6. Design of Trapezoidal fuzzy membership function

Membership can be more accurate by optimizing membership to minimize symmetry. Trapezoidal MF block uses trapezoidal elements.

$f(x; a, b, c, d) = \max(\min((x-a)/(b-a),1, (d-x)/(d-c)))$ ---(9)

The base of the trapezoid, or the left and right feet, are controlled by parameters a and d, respectively. The left and right shoulders, or verticals, of the trapezoid are governed by parameters b and c.

The relative importance of b and determines the membership function's form. The trapezium membership function is present when c exceeds b. The membership value corresponds to the membership triangle with parameters [a, b, d] when b = c.

The membership function that results when c is less than b is a triangle with a maximum value of less than 1. The fuzzy controller often receives the error (E) and deviation (dE) as inputs. Although the error can be selected by the designer, it is typically selected because in MPP, dP/dV is near to zero. Then E and dE are defined as follows:

$$E = \frac{p_k - p_{k-1}}{V_k - V_{k-1}} \qquad \text{----(10)}$$

$$dE = E_K - E_{K-1} \qquad \text{----(11)}$$

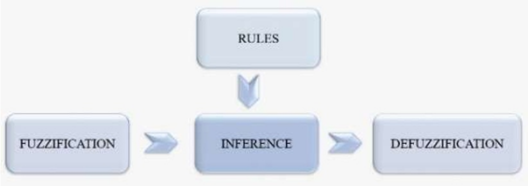


Fig. 7. Fuzzy Methodology

The process of partial membership involves three blocks. The first block, known as the 'fuzzification' block, converts numerical inputs into fuzzy sets. The second block, known as the 'inference' block, applies fuzzy rules to the inputs using if-then statements. Finally, the 'defuzzification' block uses the 'center of gravity' approach to calculate the average weighted membership.

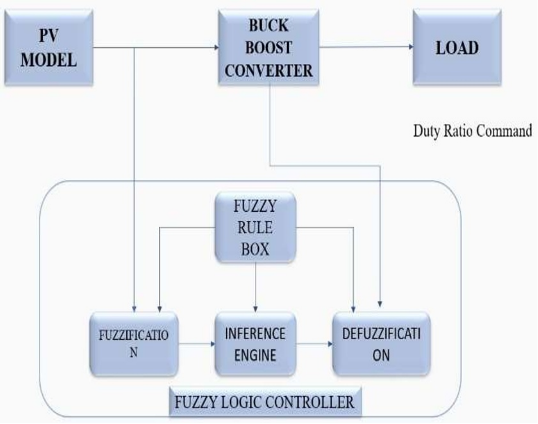
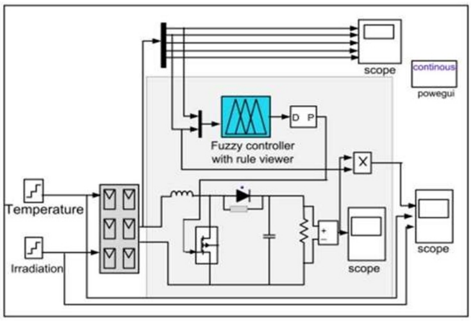


Fig. 8. Fuzzy modeling for PV

Across all fuzzy sets in output, converting the fuzzy outputs into numerical values and the modeling of the system mentioned in Fig.7, 8. And now the detailed process of the proposed system is explained below through Simulink models.

6 Integration and Grid-integration of the system



Let's now explore similarities and delve more into the suggested system. We already discussed how the PV and DFIG systems are integrated into the grid and let's delve deep into the further systems and how the MPPT is integrated with the Fuzzy logic controller etc., Let's discuss about Inc-Cond method and Fuzzy method in detail with Simulink models.

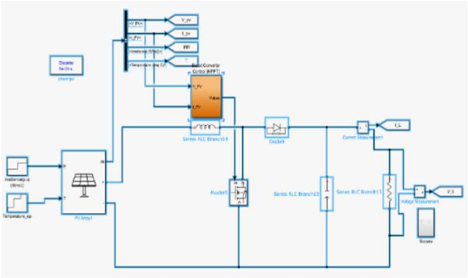


Fig. 9. Simulink model of Inc-Cond method

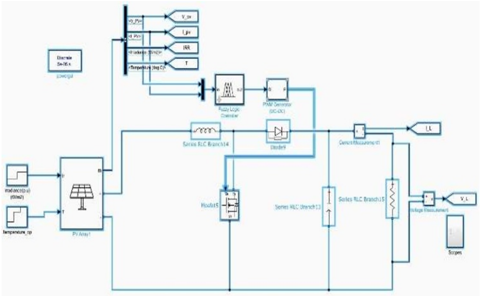


Fig. 10. Simulink model of FLC method

We discussed how Inc-Cond and fuzzy control methods work and their algorithms. Now let's examine the Simulink model. Fig.9, illustrates how a group of photovoltaic cells called PV Array blocks work together to convert sunlight into direct current (DC) power. Temperature and irradiance are inputs to the block that affect the PV array's performance. The operating point of the MPPT Boost Converter Control block is adjusted to the peak product of voltage and current to maximize power production. A diode, a capacitor, a switch, and an inductor make up the boost converter, a DC-DC converter.

The electrical characteristics of the power transformer and the load are represented by a series of RLC branches and diodes. Measurements of voltage and current are made at the load and can be utilized for control and monitoring. Figure.10 shows how the fuzzy logic controller determines the optimal duty cycle for the boost converter by evaluating voltage and current. The boost converter's MOSFET is regulated by a PWM signal from the generator. For consistent voltage and current, the RLC components filter the output. Measurements of voltage and current are made for analysis and monitoring. Oscilloscope provides a visual representation of physical activity.

There are many disadvantages in the Inc-Cond method also like sensitivity to parameter changes, tuning challenges, risk of overshoot, harmonics, etc., so, to overcome these we use fuzzy control.

Fig. 11. Fuzzy-based 10KW photovoltaic system MPPT controller simulation model

6.1 Grid integration

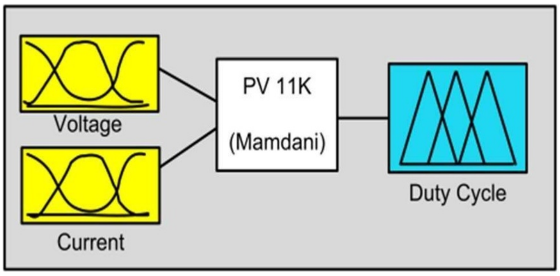


Fig. 12. Fuzzy structure of MPPT control

Based on the photovoltaic MPPT system shown in Figure 11, a fuzzy logic controller with two inputs and one function was designed using MATLAB for power conversion. The PV voltage input element function distinguishes three ranges: low voltage, medium voltage, and high voltage shown in figure 13.

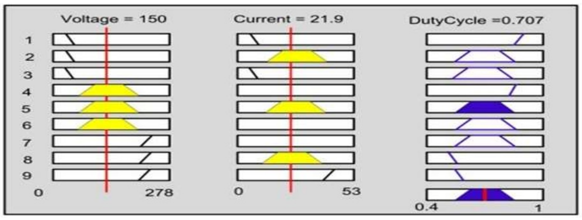


Fig. 13. Input membership function for photovoltaics

The input membership function indicates low, medium, and high current levels as shown in Fig. 14

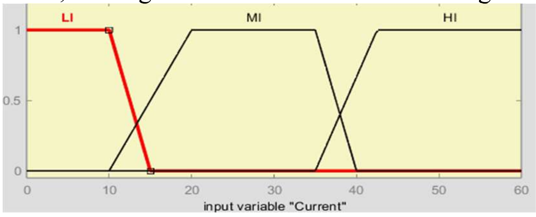


Fig. 14. Input membership function for photovoltaic

Duty membership functions are divided into three categories: low, medium, and high duty, as shown in Figure 15. The center of gravity method was used for the blurring process, and the trapezoidal method was used to create fuzzy membership for the defuzzification level. The fuzzy rules are offered in several scenarios such as low, medium, and high input, depending on the input data and analysis duty cycle are shown in Fig.16 to 18.

We have simulated the suggested fuzzy control-based PV MPPT controller in a range of climate scenarios.

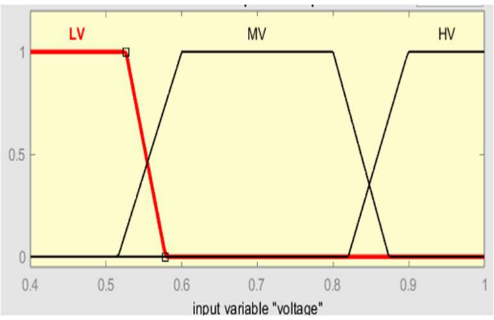


Fig.15. Membership function for Duty cycle

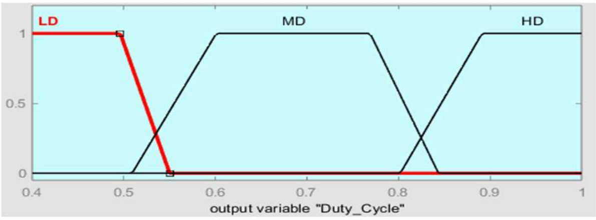


Fig.16. Rules for MPPT (Low Membership Function)

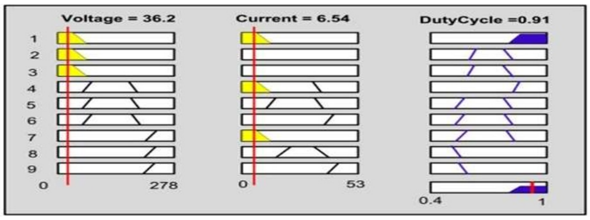


Fig.17. Rules for MPPT (Medium Membership Function)

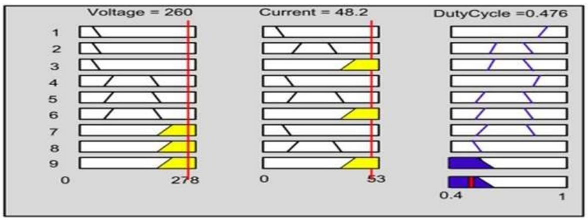


Fig.18. Rules for MPPT (higher Membership Function)

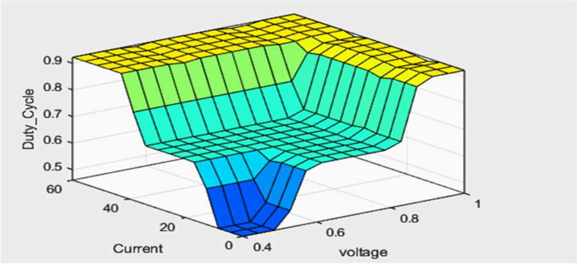


Fig.19. Surface waveform for MPPT controller

Figure 21 illustrates how the suggested simulation model analyses the PV output power waveform under the aforementioned meteorological circumstances. Fig.22. shows the voltage and current waveform of the PV boost converter. Fig.23. shows the waveform of the PV output power. The PV output waveform for the conventional MPPT controller (incremental conduction) is shown in Figure 19. Table 3 has the comparison analysis displayed.

Table 3. Fuzzy vs INC MPPT algorithm

Irradiance	Inc-Cond	Fuzzy
1000W/m2	9662W	10039W

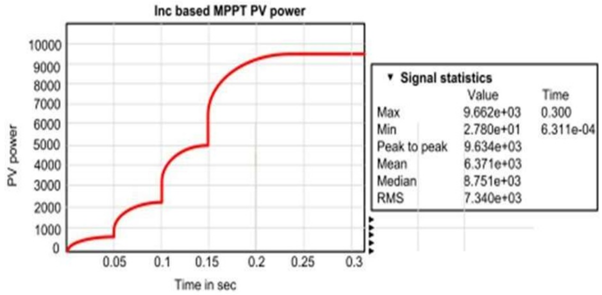


Fig.20. The waveform of PV output power using an Inc-Cond-based MPPT controller under different weather

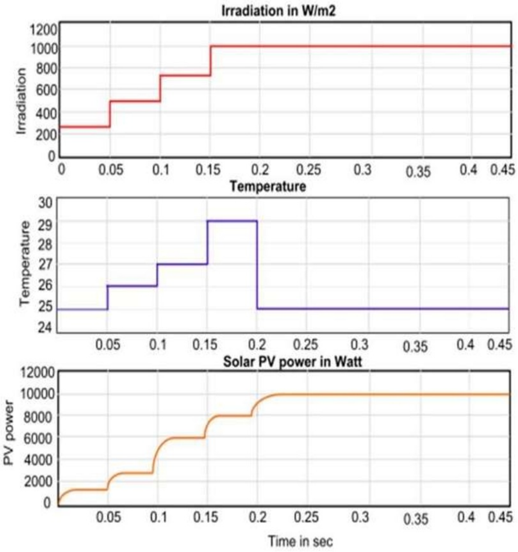


Fig.21. Photovoltaic output power waveforms at different irradiance and temperature using fuzzy-based MPPT controller

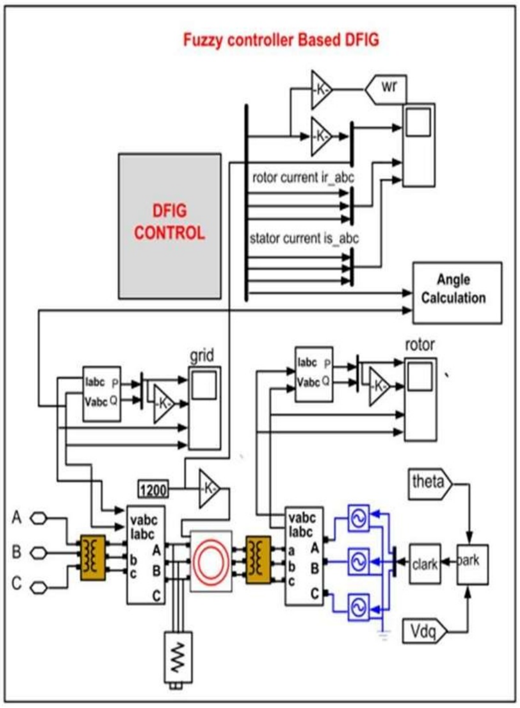


Fig.22. Voltage and current waveforms (blue: voltage) (red: current) of fuzzy MPPT controller-based boost converter at various irradiance and temperatures

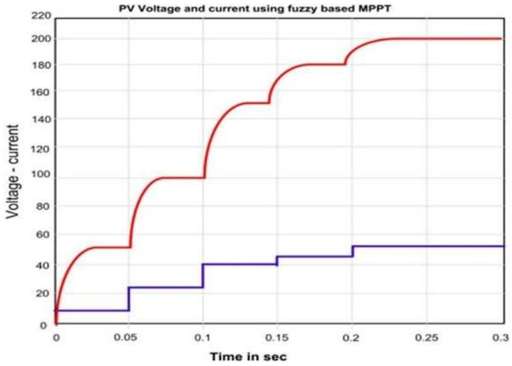


Fig.23.PV output power waveform under various weather conditions

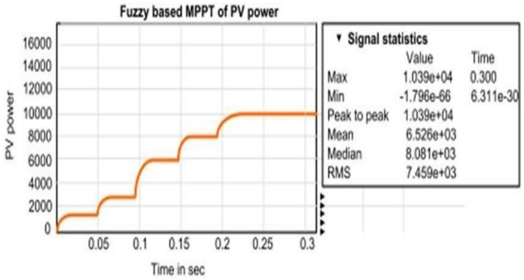


Fig.24.Simulation model of DFIG

7 Fuzzy-Based Rotor Current Control for DFIG Systems

DFIG systems control the rotor current through alternating current to achieve variable speed and maximum electrical output rate in different atmospheres (Figure 23). This technology provides speed control while reducing cost and power loss. To improve power efficiency, the DFIG rotor current controller is equipped with a fuzzy logic controller, as shown in Figure 25. The DFIG rotor current is divided into a direct axis (Id) and a quadratic axis (Iq). The controller used to control this flow was created separately using the trapezoidal force and the center of the blurring process. This controller is specially designed for direct axis current control, where the direct axis current is its control as the output member function (Figure 27. c). Fuzzy controllers are also designed for the quadratic axis current law (Figure 27.d) with input and output such as Iq as the input element and Iq as the output of the members. (Figure 27. e). Figure 28. (a) (b) Direct-axis fuzzy rules and Quadrature-axis fuzzy rules created from input data.

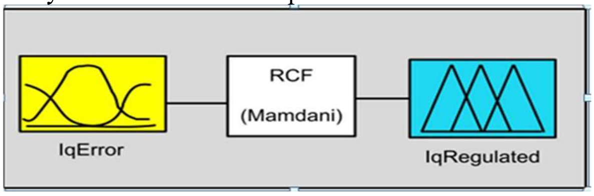
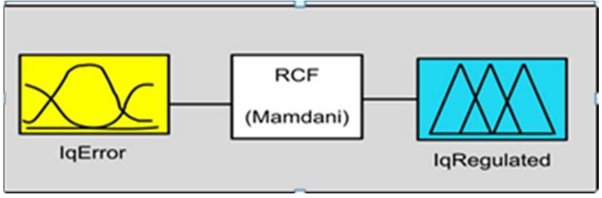
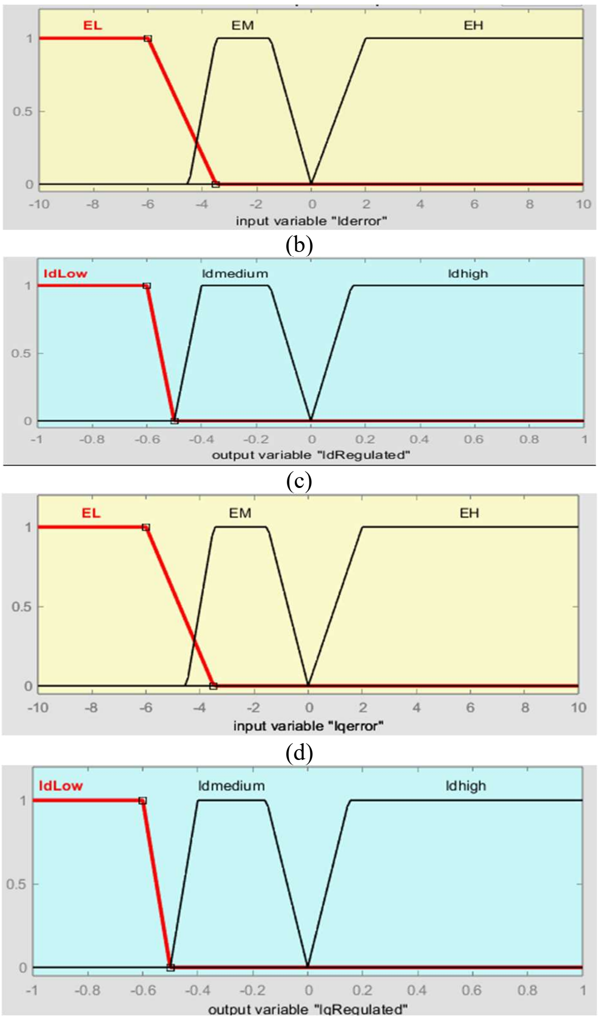


Fig.26. Fuzzy Rotor Current controller



(a)



(b)

(c)

(d)

(e)

Fig. 27. (a)Membership function for Iq controller (b) Input function for Id (c) Output function for Id (d) Input function for Iq (e) Output function for I_q

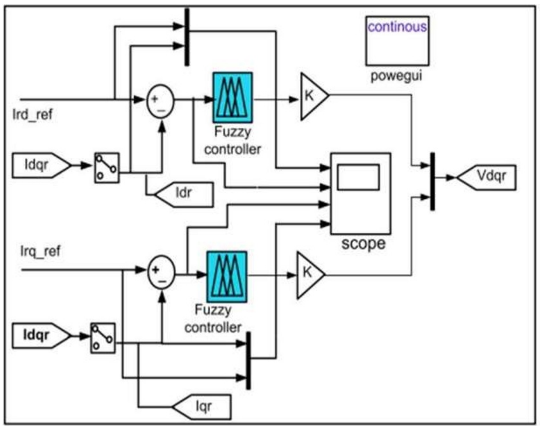
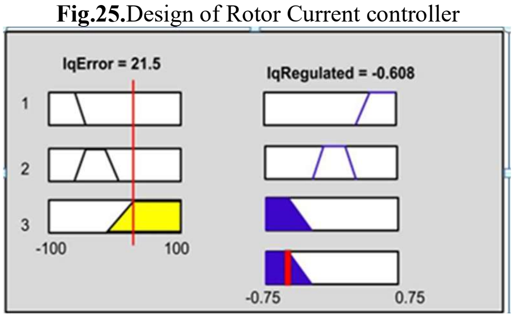
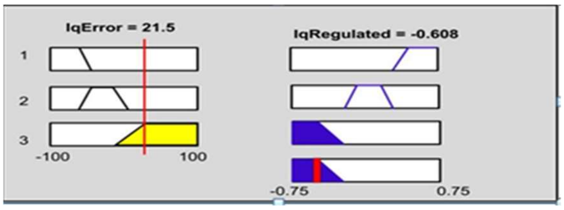


Fig.25. Design of Rotor Current controller



(a)



(b)

Fig. 28. (a) Rules for I_d current regulator (b) Rules for I_q current regulator

Table. 4. (a) (b) Comparison table for I_d and I_q

(a)

I_d error	I_d regulated
Error low	Id low
Error medium	Id medium
Error high	Id high

(b)

I_q error	I_q regulated
Error low	Iq low
Error medium	Iq medium
Error high	Iq high

8 Integration and Grid-integration of the system

Membership is represented by a solid line. Triangular, Trapezoidal, Gaussian, Generalized, Pi-Shaped, S-Shaped memberships traps, etc. There are many membership types, including. In this study, the controller is designed to use triangle and trapezoid elements. Figure 26-28 shows the membership of fuzzy variables. The simulation model of combining PV and DFIG systems is shown in Fig.29

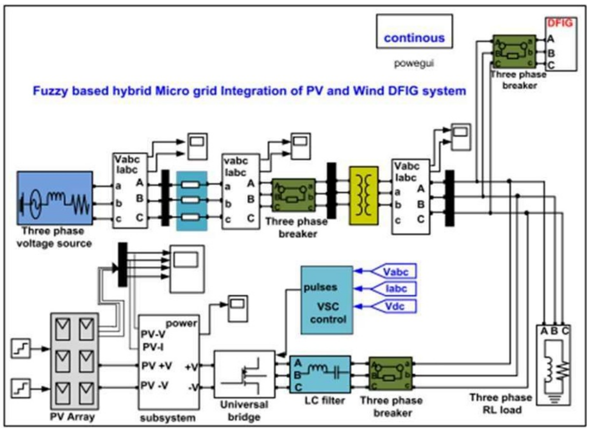


Fig. 29. Simulation model of hybrid photovoltaic/double benchmark grid-connected system based on fuzzy controller

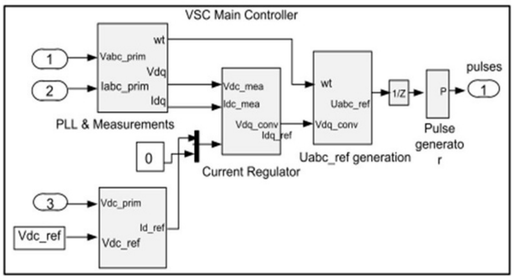


Fig. 30. Design of Voltage Source Converter

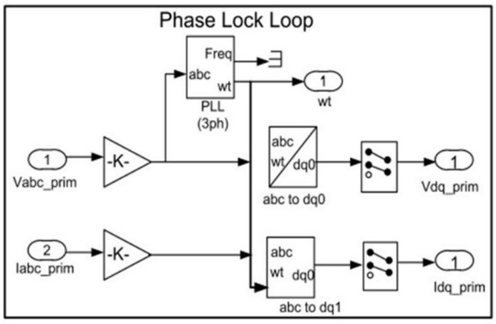


Fig. Fig. 31. Phase Lock Loop

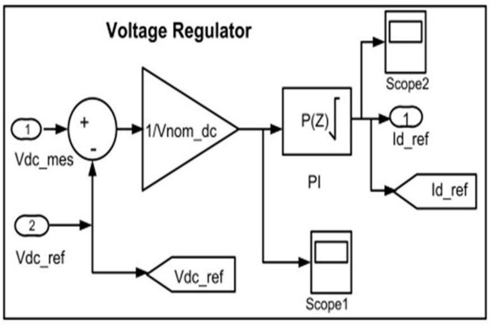
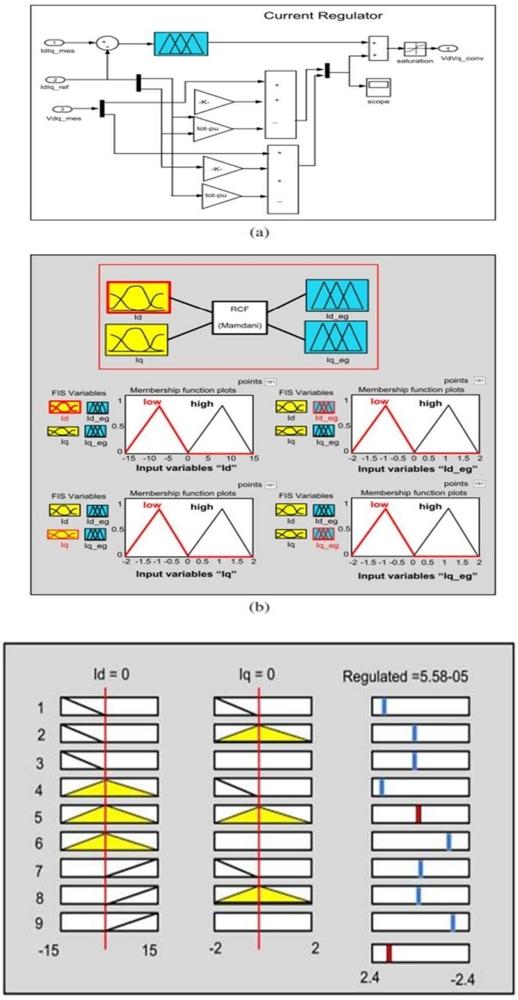


Fig. 32. Design of voltage regulator

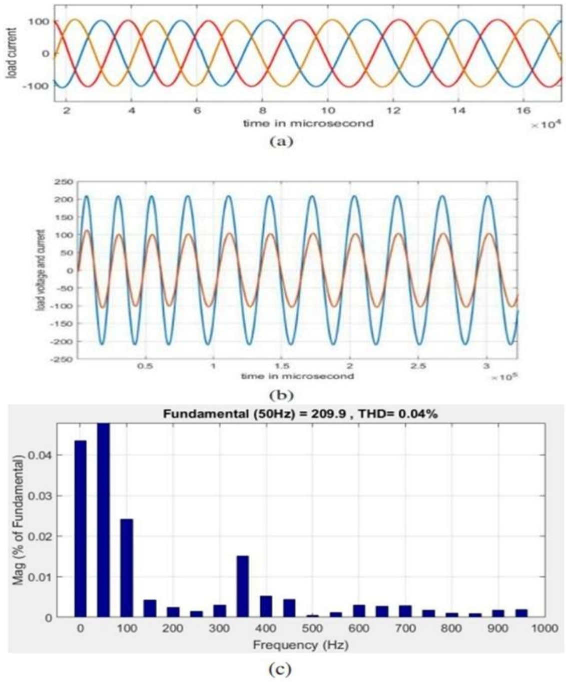


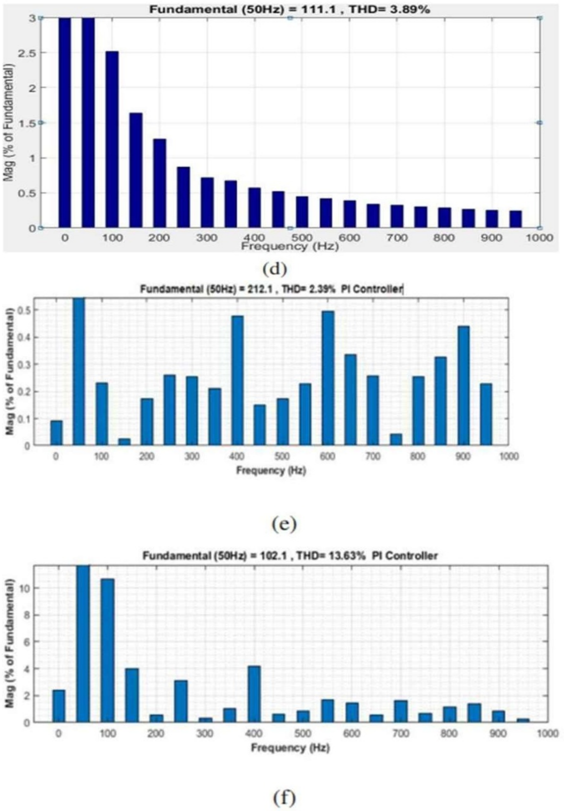
(c)

Fig. 33. (a) Design of current regulator for photovoltaic systems; (b) Ownership of the fuzzy controller and rights of the VSC current regulator; (c) Fuzzy rules of the current controller.

Figure 30 shows a power converter that plays an important role in mitigating the above problems. A power converter has three main components: a closed loop, a voltage regulator, and a current regulator. PLL is a controller that produces an output signal whose level is proportional to the level of the input signal, as shown in Figure 31. Electronic control is also used to control momentary voltage fluctuations, sags, and surges. as well as other common electrical problems such as spikes and EMI/RFI noise. Figure 32 shows how a MOSFET regulator can be used to generate PWM AC voltages at high switching frequencies.

The inverter's electrical flow will now be controlled by the regulator. The inverter produces active power even though the Ids current is outstanding; the Iq is good, but the Reactive power is absorbed by the inverter. As seen in Figure. 33(a), a fuzzy controller for a current regulator is constructed in this study. The purpose of the fuzzy logic controller is to control the current for the VSC. Two input (direct axis and quadratic current axis) and two output signals (control direct axis and quadratic axis current) are shown in Figure. 32(b), which illustrates a fuzzy controller. A fuzzy membership function was created, and the triangle approach and the center of gravity method were used for fuzzification and defuzzification, respectively. Fuzzy rules are shown in figure (33c). The direct current value means that the forward converter provides active power to the microgrid, and the four-axis current value means that the forward converter draws reactive power from the microgrid. Fuzzy control strategies have been applied to hybrid photovoltaic/wind energy systems with microgrid and voltage source conversion. According to the input signal of the PWM controller, the fuzzy output signal is given to the feedforward current regulator of the converter, thus generating a trigger pulse to synchronize the inverter and the microgrid.





(d)

(e)

(f)

Fig. 34. (a) Current waveform of grid-connected photovoltaic/double-fed wind turbine hybrid power system (b) In-phase current and voltage waveforms (c) Voltage THD analysis of the hybrid system with fuzzy controller (d) Hybrid system using Fuzzy Controller THD (e) PI current THD analysis of the hybrid system using the controller (f) Voltage THD analysis of the hybrid system using the PI controller

Figures (34a) and (34b) show the voltage and current waveforms of the hybrid PV-DFIG power system connected to the grid-based fuzzy controller, respectively. The resulting current is in phase with the load voltage as shown in Figure (34b). Finally, all the different values are measured and shown in figures (34c) and (34d). Recommended THD values for load voltage and load current are 0.04% and 3.89% respectively. The performance of the hybrid system is also evaluated using PI devices where the total harmonic distortion value scenario is measured and given in figures (34 e) and (34 f), respectively. When the PI controller is used, the THD value for the load voltage is 2.39% and the THD value for the load current is 13.63%.

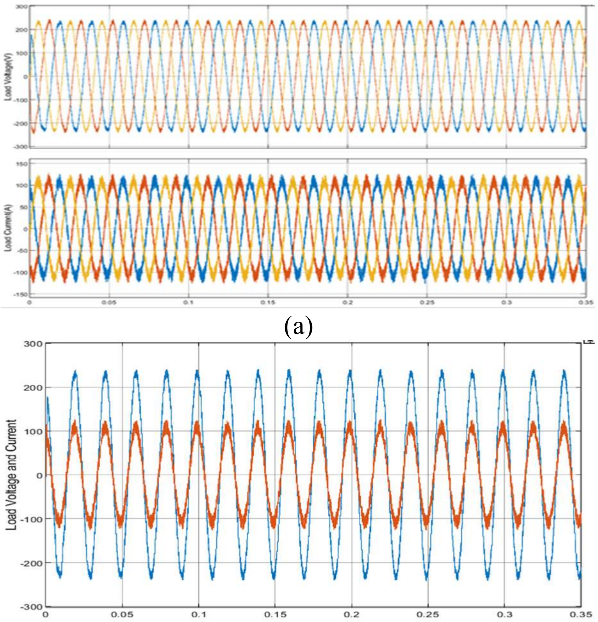
9 Methodology

Proposed Model Involves in the Following

- Research and development of maximum power point tracking fuzzy controller for a 10kW photovoltaic power generation system.
- Performance analysis under various weather conditions.
- FLC design for RCC
- MATLAB simulation of a grid-connected hybrid photovoltaic and DFIG system
- Comparison of results with conventional controllers
- Comparison of results with conventional controllers

10 Results and Analysis

The simulation results with graphs illustrate the grid-integration of PV and DFIG system comparison for both controllers are shown below.

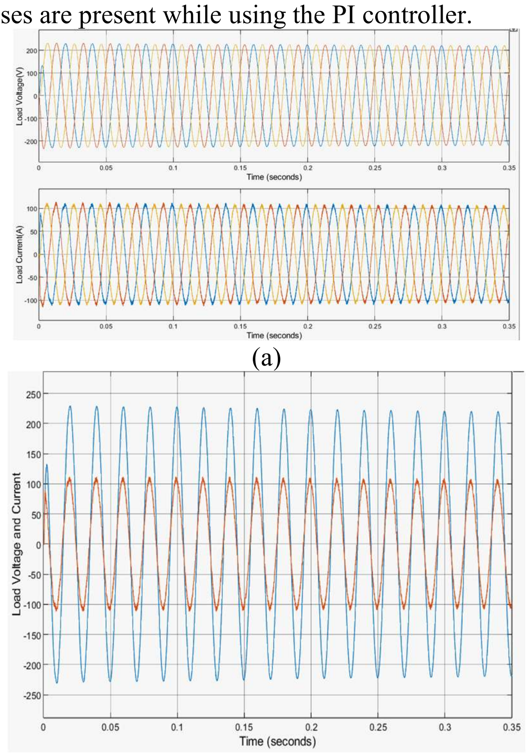


(a)

(b)

Fig. 35. (a) (b) Load voltage vs Current waveforms for PI controller

The above waveform shows how the harmonics and losses are present while using the PI controller.



(a)

(b)

Fig. 36. (a) (b) Load voltage vs Current waveforms for Fuzzy controller

Table 5. Comparison table of THD study for PI and fuzzy controllers

Parameter Value	THD of PI controller in percentage	THD of the fuzzy controller in percentage
Voltage	2.39	0.04
Current	13.63	3.89

11 Conclusion

The research investigates the integration of solar photovoltaic (PV) and doubly fed induction generator (DFIG) wind energy systems into the grid, emphasizing the possibility of increasing power quality. Fuzzy control techniques have been used to regulate and optimize power output from various renewable sources, resulting in improved grid integration. The study discovered that fuzzy control efficiently reduces voltage fluctuations, harmonics, and reactive power fluctuations. It also revealed that the integrated grid was stable and reliable. The research also emphasized the need for sophisticated control techniques such as fuzzy control to ensure smooth integration and efficient utilization of renewable energy sources. The effective deployment of fuzzy control algorithms may result in a more sustainable and robust grid system.

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