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A Novel ANFIS Controller Based Distributed Power Flow Controller for Grid Interfaced Hybrid System

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ABSTRACT: This study suggests a new controller for grid-interfaced hybrid systems called the Adaptive Neuro-Fuzzy Inference System (ANFIS). Creating a Distributed Power Flow Controller (DPFC) that can efficiently control power flow and enhance system stability is the goal. In order to manage the intricate non-linear dynamics of hybrid systems, the suggested ANFIS-based DPFC offers real-time control techniques. To show how well the suggested controller performs in preserving stability and enhancing the overall performance of the grid-interfaced hybrid system, simulation tests are conducted to compare its output with that of traditional controllers. MATLAB/SIMULINK software is used to compare and assess the performance of the suggested method with the standard way in terms of total harmonic distortion.

KEYWORDS: Grid-connected PV and wind energy systems, distributed power flow controllers, fuzzy logic controllers, and ANFIS controllers.

I. INTRODUCTION

Electricity consumption has been steadily rising in everyday activities. However, the reliance on non-renewable energy sources for power generation is detrimental, contributing to ozone layer depletion [1]. Non-conventional sources are essential to the current energy generation systems since they help solve environmental issues while meeting electrical demand [2]. These renewable energy sources have three key benefits: they are inexpensive, pollution-free, and require less upkeep. There are more renewable energy systems on the market, but they are still important because of their straightforward design, accessibility to environmental resources, and extremely effective circumstances [3]. Conversely, all renewable energy systems don't operate like this. Energy sources that are important to hybrid systems include wind and solar systems [4]. PV systems are not inherently stable with respect to time, location, season, or weather, on top of being incredibly expensive to install. Variations in meteorological circumstances impact the solar system's output [6]. Consequently, MPPT techniques were used to maximize output and boost solar panel efficiency [7]. Wind energy systems, depending on the natural environment, are an important renewable energy source in addition to solar power systems. The amount of wind that exists in the environment determines the percentage of electricity generated [8]. The outputs produced by wind systems are impacted by variations in the weather [9]. Thus, MPPT techniques are applied in order to maximize production and boost the wind system's efficiency. The solar system was integrated with the VSC to ensure alignment of frequency levels and system rates. Employing a conventional PWM technique, a control diagram for the inverter was formulated, with reference signals tailored to meet the requirements of the grid [10]. Presently, extensive and sophisticated electric power networks are in operation. In interconnected power systems, fluctuations in power demand cause adjustments in tie-line power exchange and regional frequency. Without proper oversight, achieving a balance between generation and demand becomes a formidable task [11]. Therefore, a control mechanism is necessary to address the impacts of irregular load fluctuations and maintain frequency at the standard level. This framework has also illustrated the fundamentals of a reorganized power system [12]. ANFIS-based system integrates neural networks and fuzzy logic for adaptive control, offering robustness and efficiency in various applications [33]. Section 2 outlines the system configuration, Section 3 clarifies the controlling topology, Section 4 outlines the suggested controlling topology, Section 5 shows the findings and discussion, and Section 6 wraps up the work.

II. SYSTEM CONFIGURATION

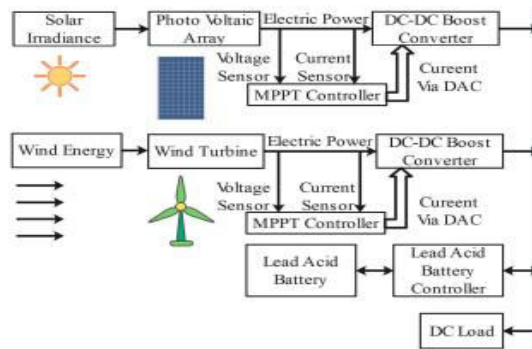


Figure 1: Block Diagram of Grid interfaced Hybrid system

A conventional micro grid system's block diagram is displayed in Figure 1. Incorporating a bidirectional battery bank improved power supply reliability. The PV, wind, and battery systems are connected in this configuration via the DC bus. An inverter is used to connect these systems to the grid system. Maintaining synchronization between the hybrid system and the grid is the aim of this inverter [13]. The various loads were run on the suggested hybrid system.

III. SOLAR PV ARRAY

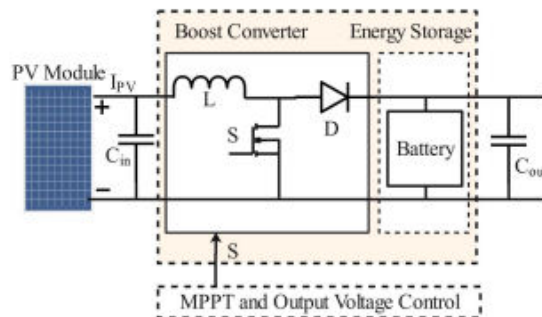


Figure 2: Structure of PV-Boost

Optimizing energy extraction and conversion for increased efficiency is possible with a PV array coupled to a boost converter that uses MPPT. With the MPPT algorithm, the PV array's operating point is continuously checked and adjusted to optimum power output under different sunshine conditions. Effective energy transfer to the load or grid is then ensured by the boost converter, which raises the voltage from the PV array to the required output voltage [14]-[15]. This setup is especially useful for applications when the PV array's output voltage is lower than the necessary voltage, like grid-tied systems or battery charging.

By dynamically adjusting the voltage and current levels, the boost converter with MPPT utilization enables the solar PV system to operate at its peak performance, even in challenging environments like partial shading or temperature fluctuations. Temperature and sun irradiation both affect the resulting DC voltage. To keep the DC voltage from the solar system steady, an MPPT-based DC-DC boost converter is advised; Figure 2 illustrates this.

The integration of MPPT with a boost converter enhances the overall efficiency and reliability of solar power generation, contributing to the widespread adoption of renewable energy technologies and the transition towards a more sustainable energy future [16]-[17].

Parameter Variable	Ratings
Input Voltage Range DC (Min)	150V
O/P voltage range DC (Max)	350V
Switching Frequency up to	100KHz
Inductor (L)	5mH
Capacitors (C)	1500uF
IGBT	1200V/100A

Table 1. Specifies the parameters of the boost converters

IV. WIND POWER GENERATION

Wind energy is harnessed to generate electricity through the use of a SCIG in wind power generating. By removing the need for a gearbox and connecting the SCIG directly to the wind turbine rotor in this setup, maintenance requirements and complexity are decreased [18]-[19]. The electricity generated by the SCIG is sent to a transformer, which steps up the voltage for efficient transmission over long distances. This higher voltage reduces transmission losses, ensuring that the electricity generated by wind turbines can reach distant consumers without significant energy wastage [19]-[20]. After transformation, the electricity is fed into the grid, where it integrates with other sources of electricity to meet consumer demand. Grid operators manage the flow of electricity, balancing supply and demand to maintain grid stability [21]-[22]. The integration of SCIGs with transformers and the grid enables wind energy to contribute to the renewable energy mix, reducing reliance on fossil fuels and mitigating climate change while providing a reliable and sustainable source of electricity. Fig. 3 depicts the standard wind turbine system structure using a conventional generator. The power produced by the wind turbine system is the mathematical representation of the wind energy system, as stated in (1).

$$P_{mech} = \frac{1}{2} C_p(\lambda, \beta) m A \rho v^3 \quad (1)$$

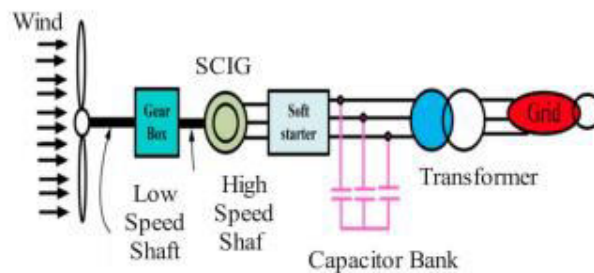


Figure 3: Structure of WECS connected to Grid

V. PERTURB AND OBSERVE BASED MPPT

A technique used in solar photovoltaic (PV) systems to track the MPP of the PV panel is called P&O (MPPT). When certain environmental factors, such as temperature, irradiance, and shade, are taken into account, the MPP is the point at which the PV panel produces its maximum power output [23]-[24]. In order to observe changes in power output, the P&O MPPT algorithm modifies the PV panel's operational voltage or current. The algorithm then compares the power output at the perturbed and original operating points and adjusts the operating point in the direction of the perturbation that increases the power output. This process is repeated until the MPP is reached. Using instantaneous PV power, the obtained PV power was calculated. These findings allow for the measurement of the necessary reference current signal. Because of this intricacy, the controller design lends itself nicely to solution through optimization algorithms [26]. Optimization algorithms for electronic design is a well-established topic of study that has the potential to offer high-complexity designs an ideal answer [25]-[26].

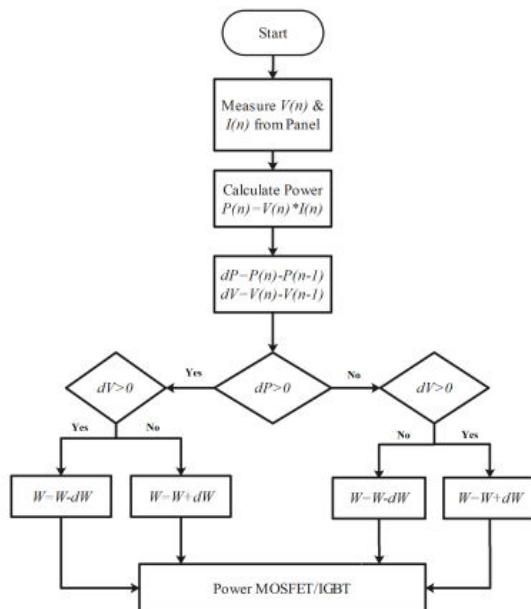


Figure 4: Perturb and Observe based MPPT

VI. INVERTER CONTROLLING TOPOLOGY

Devices for improving power quality include distributed power flow controllers (DPFCs). The components of this system are an a-shunt converter and a two-converter series converter, as seen in Figure 5. Whereas voltage harmonic correction for the load and microgrid is provided by a series converter, current harmonic compensation is provided by a shunt converter [27]. A double loop of current controllers was used to build this inverter control scheme [28].

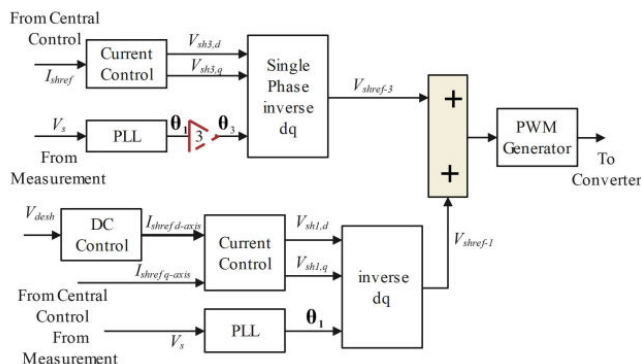


Figure 5: Block Diagram of DPFC controlling topology

Diagram for converter control is shown in Figure 6. For this controller, measurements were taken of the current, system voltage, and load. This d-q transformation was obtained by applying Park's approach [29] to these load currents. The grid's active power comes from the combination of the hybrid system's power, loss, and load. The power of grid obtained at grid side can be depicted as

$$P_g = P_L + P_{SL} - P_{PV} \quad (2)$$

With the help of an inner current controller, this power is converted into the reference current signal (i^*_{s1}). The measured signal is compared with the reference current for triggering the switch. The DPFC's parameters are listed in Table 2.

Parameter Variable	Ratings
DC Link capacitor (CDC)	220 pF
DC Link voltage	640 V
Carrier Frequency	2.08 KHz

Table 2: Link Capacitor Specifications

VII. CONTROL TOPOLOGY WITH PI CONTROLLER

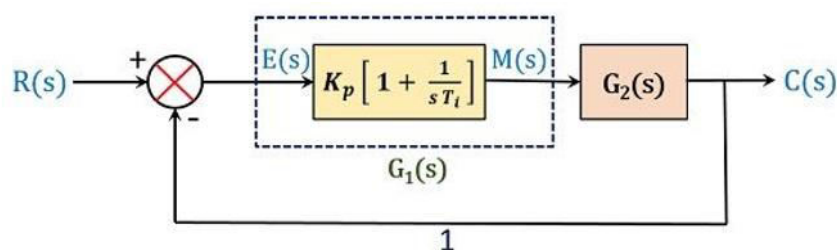


Figure 6: PI CONTROLLER

A Proportional-Integral (PI) controller is a feedback control mechanism commonly used in engineering and automation systems. The difference between the observed process variable and the desired setpoint is used to adjust the output. While the proportional component yields an output proportionate to the error, the integral component integrates the error over time to eliminate steady-state errors. By combining proportional and integral actions, the PI controller achieves both quick response to changes and steady-state accuracy. It is widely used in various applications such as temperature control, motor speed regulation, and process control systems for its simplicity, effectiveness, and stability.

VII. CONTROL TOPOLOGY WITH FUZZY LOGIC CONTROLLER

A FLC operates by using linguistic variables, fuzzy sets, and a set of fuzzy rules to process imprecise input data and produce corresponding output actions. It begins by fuzzifying crisp input values into linguistic terms, then applies fuzzy logic inference to evaluate the degree of membership for each fuzzy rule. Aggregating these rule outputs, it determines a fuzzy output set [30]-[31]. Finally, defuzzification converts the fuzzy output set into a crisp output value.

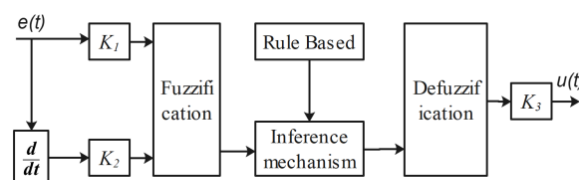


Figure 7: Block Diagram of DPFC controlling topology.

This iterative process enables FLCs to handle complex and uncertain systems, providing robust and adaptable control solutions across various applications such as automotive systems, consumer electronics, and industrial automation [32]. Here, an if-then statement is used to define the rules, as seen in Fig. 7.



VIII. PROPOSED ANFIS CONTROLLER

A key component of a DPFC system that enhances grid-interfaced hybrid system performance is an ANFIS controller. By integrating the benefits of neural networks and fuzzy logic, ANFIS manages the DPFC's functioning with efficiency. Initially, the ANFIS controller fuzzifies input signals, converting them into linguistic variables. Then, it utilizes adaptive neural networks to evaluate fuzzy rules, adjusting parameters based on training data to optimize system performance. The rule outputs are aggregated, and defuzzification produces crisp output signals, guiding the DPFC to provide precise control actions [33].

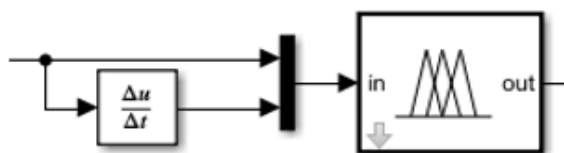


Figure 8: DPFC BASED ANFIS CONTROLLER

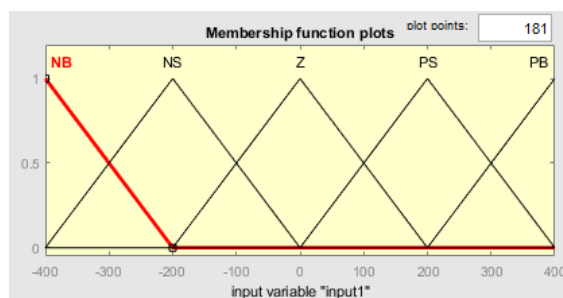


Figure 9: Membership Function a

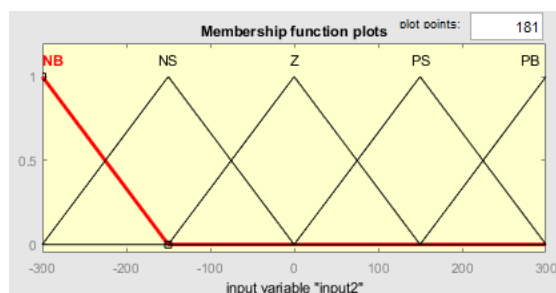


Figure 10: Membership Function b

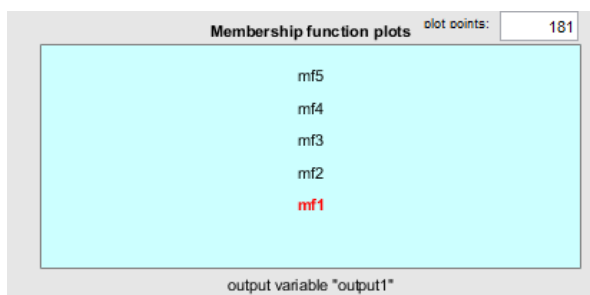


Figure 11: Input-1, Input-2 and Output of ANN System

Through its adaptive and learning capabilities, ANFIS enhances the efficiency and stability of grid-interfaced hybrid systems, contributing to improved power quality, reduced losses, and increased reliability in the operation of distributed power flow control systems. Figure-8 Describes the structure of ANFIS Controller [33].

IX. RESULTS AND DISCUSSION

The framework model depicted in Figure 9 is developed using MATLAB/SIMULINK and includes the PI, FLC, and ANFIS controllers. Two distinct case studies were used to model and test the suggested grid-interfaced hybrid system with a DPFC controller.

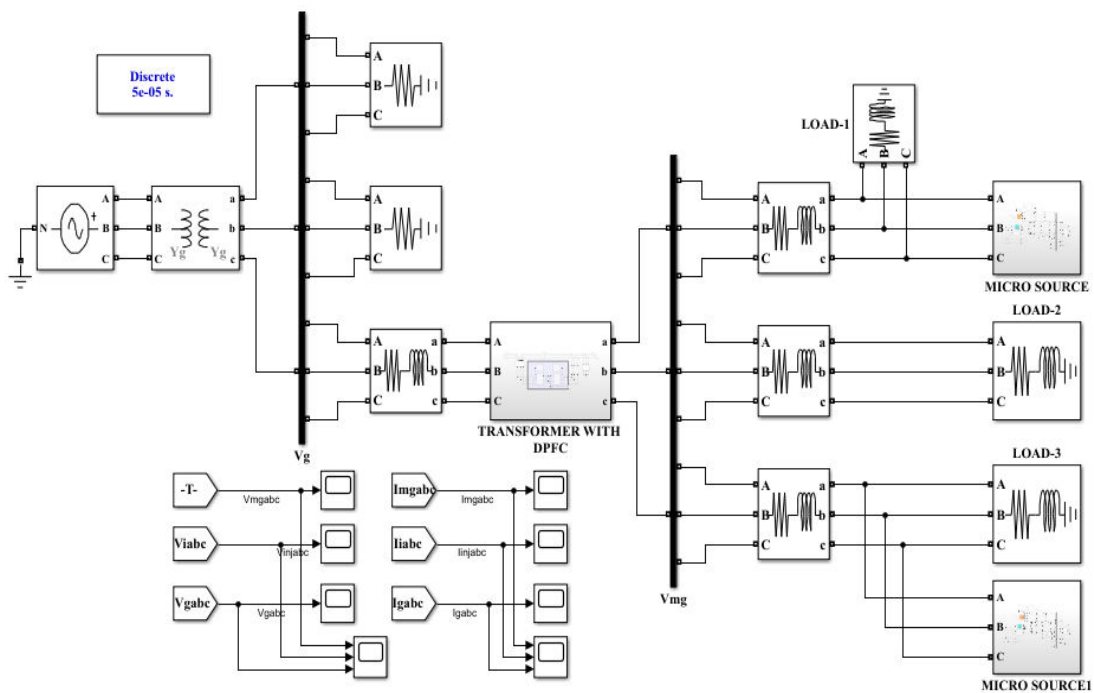


Figure 12: Simulink Model of the proposed method

Tables 3 and 4 present the specifications of the hybrid system that combines solar and wind power.

Parameter Variable	Ratings
Maximum Power	100W
Voltage at max Power	18.7V
Current at max Power	5.35A
Open Circuit Voltage	22.32V
Short Circuit Current	5.65A
No. of panels	10
No. of strings	I
Type of Cell	Polycrystalline Silicone

Table 3: PV System parameters



Parameter Variable	Ratings
Rated power output (W)	5000
Peak power output (W)	6800
Rated Voltage	415
Cut-in- Speed (m/s)	2
Nominal wind speed (m/s)	8
Cut-out- Speed (m/s)	18
Rated Rotor Speed (RPM)	250
Generator Efficiency	0.95
Noise Level	<30db
Number of Blades	3
Rotor diameter (mm)	3600
Blade Material	Glass fiber
Generator Type	SCIG
Cp value at max	0.18

Table 4: WECS Specifications

CASE-1: ENHANCING POWER QUALITY IN A HYBRID SYSTEM THROUGH THE APPLICATION OF PI, FLC, AND ANFIS-DPFC:

Here, a DPFC-PI, FLC and ANFIS is used to evaluate the suggested system, and Fig. 10 displays the results.

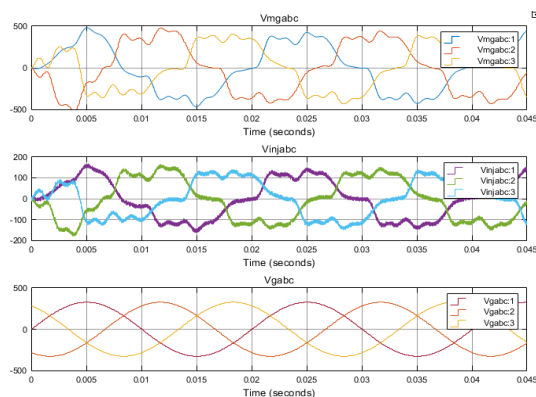


Figure 13: Voltages of Grid, injected under microgrid distorted condition micro grid voltage using PI

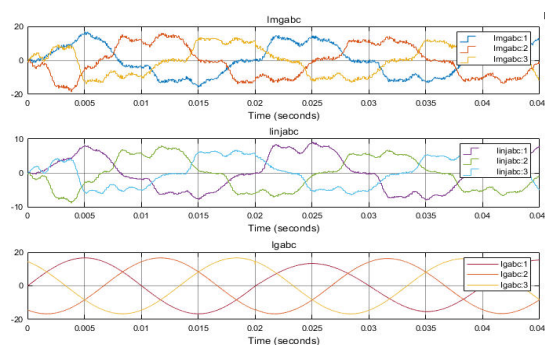


Figure 14: Currents of Grid, Injected and microgrid using PI

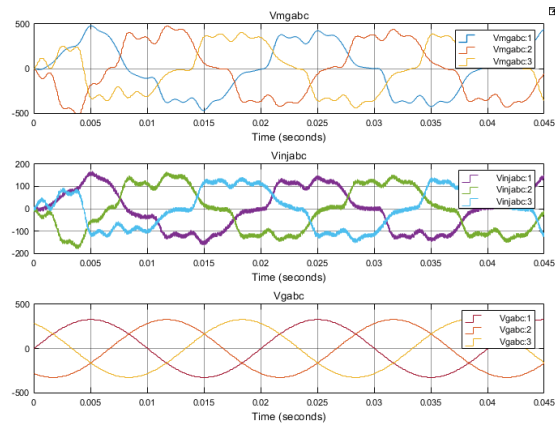


Figure 15: Voltages of grid, injected using FLC with microgrid distortion condition

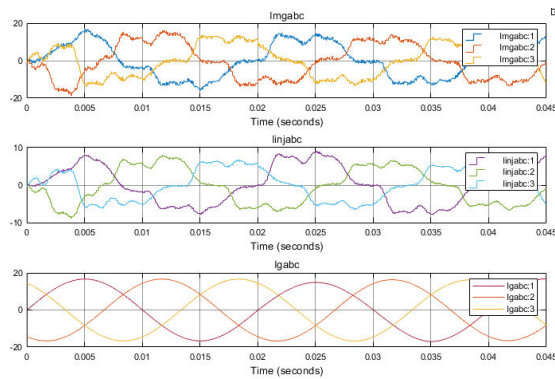


Figure 16: Currents of grid, compensated and injected using FLC

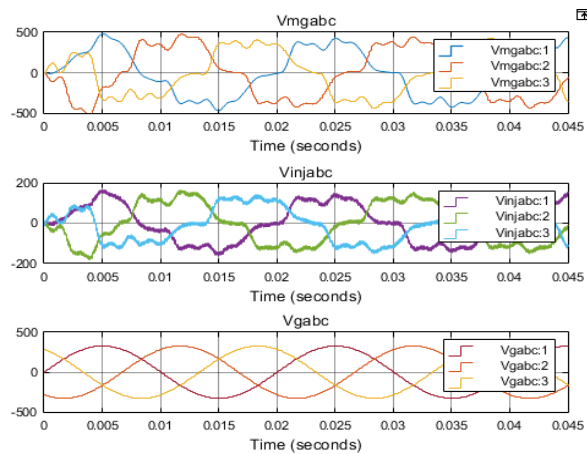


Figure 17: Voltages of Grid, injected and adjusted using ANFIS

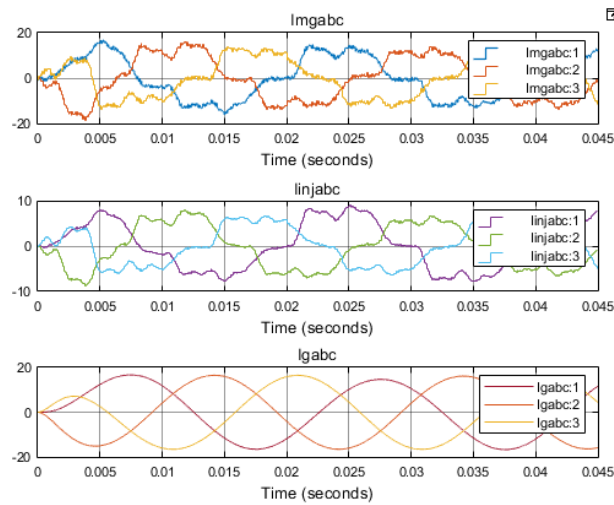
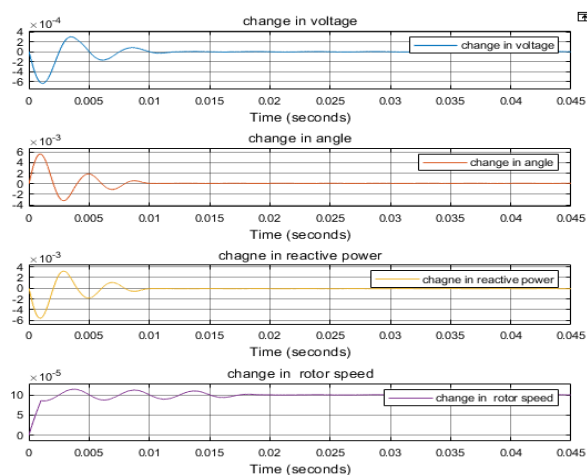


Figure 18: Currents of grid, injected and adjusted using ANFIS

The above figure 15, 16, 17 describe the voltages obtained at the DG side, injected and grid. Here, the voltage distortions that affect the proposed grid-connected system are assessed at the grid side in an effort to reduce the distortions generated. Figure 11b,d,f displays the injected current from the DPFC parallel converter at fundamental and third order frequencies in addition to the unbalanced current resulting from the unbalanced load. The rectified current of the grid system is displayed in Fig. 11. The suggested system is connected to various load conditions, including linear and unbalanced loads. The shunt converter of the DPFC serves to alleviate the unbalanced circumstances caused by the use of nonlinear loads, which in turn affects the microgrid current. The non-linear and unbalanced loads created harmonic distortion of the grid current, which was compensated for by a DPFC controller. Compared to the PI and FLC, the ANFIS-based system exhibits fewer distortions.

CASE 2: IMPROVEMENT OF TRANSIENT STABILITY IN A HYBRID SYSTEM USING PI, FLC AND ANFIS:

In this instance, PI, FLC, and ANFIS controllers were used to test the suggested hybrid system converter control diagram and increase the hybrid system's stability.



a) Change in Voltage, angle, Reactive Power, Rotor Speed using PI Controller

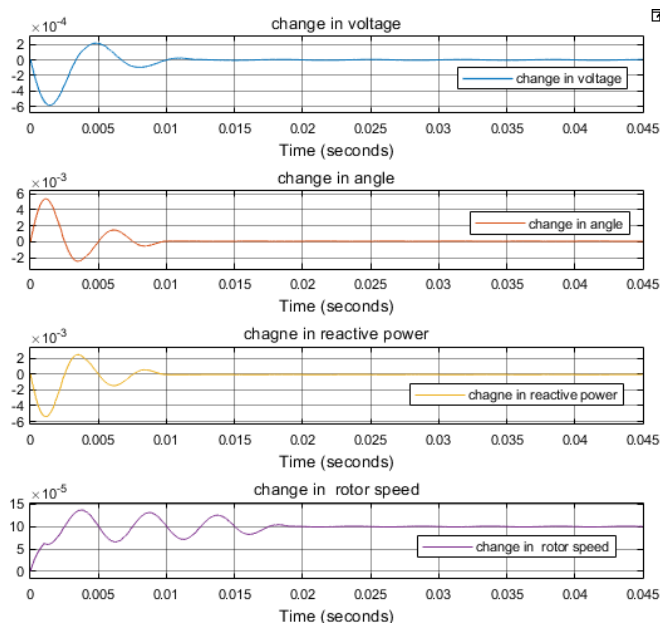


Figure 19: Change in Voltage, angle, Reactive Power, Rotor Speed using FLC Controller

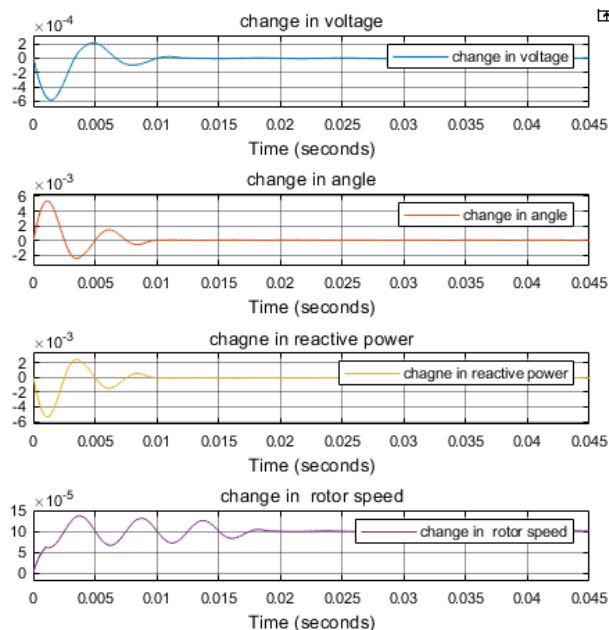


Figure 20: Change in Voltage, angle, Reactive Power, Rotor Speed using ANFIS Controller

Changes in supply, load, or system parameters are the primary sources of stability issues. It was possible to observe the stability of the generators' voltage, rotor speed, reactive power, and angle by measuring the simulation results displayed in the previous Figures.

Compared to the PI and FLC, the ANFIS-based system exhibits fewer distortions.

Parameter\Controller	Using PI	Using FLC	Using ANFIS
Grid Current	4.27 %	3.91 %	2.31 %

Table 5: THD Comparison Table

The above table describes the THDs values obtained in the grid current by using Different Controllers. The ANFIS Based system has better reduction of THD compared to the PI and FLC.

X. CONCLUSION

In this work, the design and implementation of ANFIS based DPFC has been employed in grid interfaced hybrid system. By integrating an innovative ANFIS controller, this approach merges the advantages of conventional power flow control and fuzzy logic control methods. Implementing a distributed framework bolsters system resilience and minimizes susceptibility to single-point failures. Through comprehensive simulations and experiments, the efficacy of the proposed method in enhancing power flow control and system stability is demonstrated. The ANFIS controller's adaptive nature and ability to learn from data contribute to its effectiveness in optimizing system performance. Overall, this project presents a robust and reliable strategy for improving the operation of grid-interfaced hybrid systems, offering potential benefits in terms of enhanced efficiency, reduced losses, and increased reliability in real-world applications.

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