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INTEGRATION OF DPFC AND FUZZY LOGIC CONTROLLER BASED GRID HYBRID SYSTEM FOR ENHANCED PERFORMANCE

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ABSTRACT

This paper's primary goal is to present a structure for the design and modelling of a PV-wind hybrid system and its control techniques. These control strategies goal is to manage ongoing adjustments in the hybrid system's operational needs, including changes occurring in power. Power dependability in distribution systems is sustained through the delivery of energy. In this project, a hybrid PV and wind energy system was integrated to the designed hybrid model. To get the most from the designed system, strategies for maximum power point tracking (MPPT) have been presented. This project also concentrated on enhancing the hybrid system's stability. We provide a new control scheme call the distributed power flow controller (DPFC) operation with an optimization technique called the lion optimization algorithm (LOA) technique to advance the quality and transient stability of the planned system. The use of a DPFC controller in a grid-connected system led to the first development of this LOA control approach. Signals from the system's voltage and current parameters were used to build the control approach. This project applied fuzzy logic and lion optimization methods to fine-tune these parameters. The proposed controller-equipped system was evaluated in MATLAB/Simulink, and the outcomes be contrasted.

INDEX TERMS: Distributed Power Flow Controller, Fuzzy logic controller, grid interconnected, Lion Optimization Algorithm, PV system and wind energy system.

I. INTRODUCTION

The need for electrical energy has risen quickly in the current situation. Pollution and greenhouse gas emissions are brought on by the usage of conventional power generation methods, such as gas, coal, and nuclear power plants. Non-conventional sources are crucial to the current energy generation systems in order to solve these ecological threats and meet electricity demands. These renewable energy sources' key benefits are that they produce little pollution, need little upkeep, and are inexpensive. Although there are more renewable energy systems on the market, wind and solar energy systems are particularly important due to their straightforward design, accessibility to environmental resources, and highly efficient conditions. In hybrid systems, PV and wind energy systems are important primary energy sources. Compared to other renewable energy sources, photovoltaic systems are one of the most practical renewable energy systems. Solar systems are quite expensive to build, and photovoltaic systems are not inherently reliable with respect to time, place, season, or weather. The solar system's production is impacted by changes in the weather. Hence, MPPT techniques were used to maximise production and improve the effectiveness of the solar panel. Wind energy systems are another important renewable source for PV systems, depending on the available natural conditions. The amount of electrical energy produced depends on how much wind there is in the environment. Weather variations have an impact on the outputs produced by wind systems.

Therefore, MPPT techniques are used to maximise production and improve effectiveness of the wind system. The system needs to stay in sync with the grid. To match the frequency levels and system rates, the solar system was connected to a voltage source inverter. The control diagram for the inverter was created via a basic PWM technique, and the reference signals were selected from the grid characteristics. Electric power networks are currently very vast and complicated. Both territorial recurrence and tie-line power exchange vary in an interconnected power framework as a power burden request varies arbitrarily. Harmony between burden and age is challenging to maintain without control. Accordingly, a control framework is essential to reduce the effects of erratic load variations, preserve recurrence at the standard value, and have proven the fundamental concept of a restructured power system.

II. GRID INTERCONNECTED NETWORK

A normal microgrid system is shown in fig.1. A microgrid combines wind and solar energy sources. A bidirectional battery bank was also deployed to increase the power system's dependability. The PV, wind, and battery systems in this instance are connected at the DC bus, and an inverter is used to connect them to the grid system. This inverter's function is to maintain synchronisation between the hybrid system and the grid. The various loads were run by the suggested hybrid system.

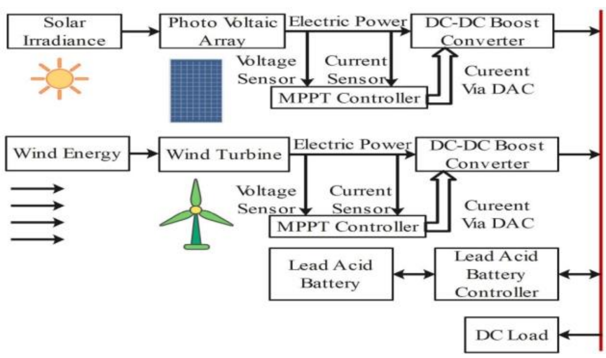

Fig.1 Schematic diagram of microgrid system.

A. PV SOLAR SYSTEM

Because of its availability in nature, dependability, and affordability, the solar energy system has played a significant part in the history of renewable energy compared to other disrupted energy sources. Solar cells use the photon effect of the sun's irradiance to produce electrical energy. Electric current flows initially from solar cells and is afterwards turned into PV voltage with the aid of an analogous electric circuit. Temperature and sun irradiation both affect how much DC voltage is achieved. An MPPT-based DC-DC boost converter is developed in order to acquire a constant DC voltage from the solar system. The MPPT's goal is to follow the solar system's maximum power. These cells were arranged in series and parallel to meet the required voltage and current ratings.

A PV system's instantaneous power is tracked by MPPT. Using the PV voltage and current, the PV power was determined. A P&O MPPT is suggested for use in this system. The reference signals are regulated using voltage and current controllers. These reference signals are then used by a standard PWM controller to produce the duty cycle necessary for the DC-DC converter. The DC-DC boost converter terms are as follows:

1. DC input voltage is 150V
2. DC output voltage is 350V
3. Switching frequency is upto 100KHZ
4. Inductance is 5Mh
5. Capacitance is 100 µF
6. IGBT has 1200V/100A.

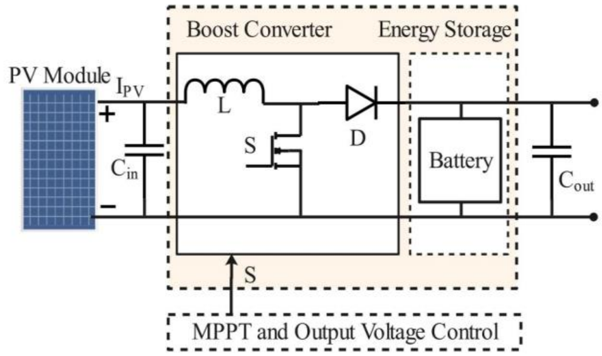

Fig.2.Power converter used PV system

B.WIND ENERGY SYSTEM

Another important factor in this unbalanced energy system is wind turbines. Due to the two-stage energy conversion process used by wind in nature, wind speed is first converted to mechanical energy by turbine blades and then to electrical energy by an electrical generator. The wind turbine also includes a gearbox system to change a low-speed shaft into a high-speed shaft along with these parts. In order to increase reliability, a pitch angle controller was used to spin the wind blades in response to the wind's direction. A wind vane was used to gauge the wind's velocity as it approached the wind turbine. The structure of a general wind turbine system with a conventional generator is shown in Fig. 3 shows the typical layout of wind turbine system using a traditional generator..

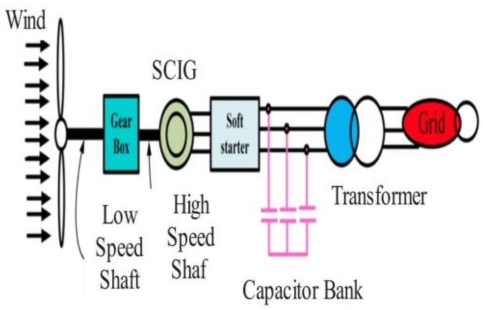

Fig.3. SCIG wind turbine.

The power generated by the wind turbine system is expressed in the mathematical modelling of the wind energy system as in the equation (1).

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

The two types of generators that are readily available in the market are Induction generator and a Synchronous generator. In this instance, the wind turbine produced electricity using a squirrel-type induction generator. To synchronise with the AC grid, an AC-DC-AC converter was employed.

C. PERTURB AND OBSERVE MPPT ALGORITHM

Many different research and technology sectors experience optimization issues on a regular basis. Due to the real and realistic nature of the goal function or model boundaries, such problems can occasionally be exceedingly complex. An goal function subjected to complex, nonlinear characteristics with significant parity and/or parity limits is minimised or maximised in a typical optimization problem. In the P&O method, the structure monitors changes in the array voltage before determining how the output power has changed. A flowchart representation using P&O and MPPT algorithm is shown in figure 4.

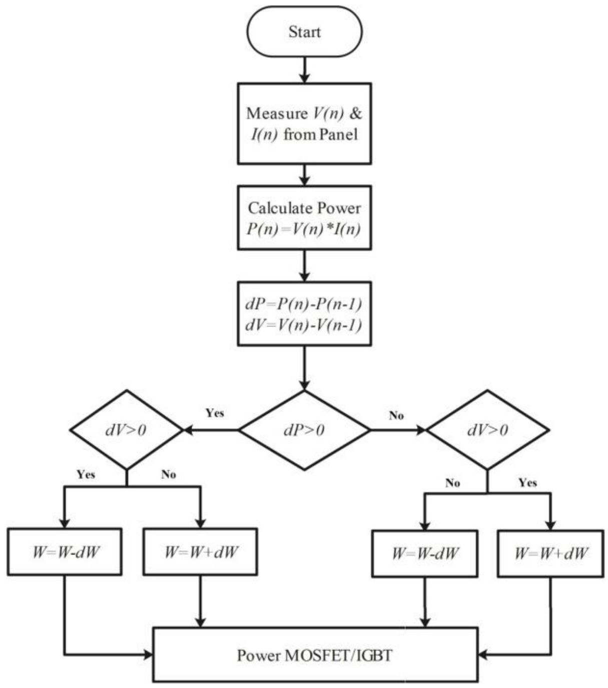

Fig.4. P&O approach representation in a flowchart.

The voltage and current of the PV panel are measured, and the PV power is calculated in the flowchart. Instantaneous PV power was used to gauge the obtained Photo Voltaic power. The necessary reference current signal is measured as a result of these findings. This cycle was continually repeated. This Perturb and Observe technique's primary drawback is, it cannot be used to account for ongoing changes in environmental factors like irradiance and sunlight. To produce a better output, the current output is continually compared to the prior output. Because of its complexity, optimization methods are a good choice for solving the controller design. An optimal solution for high-complexity designs is on the horizon thanks to a well-established branch of research called electronic design using optimization algorithms. The MPPT algorithm (perturb and observe) in this paper shows how the solar panels track their maximum output.

D. INVERTER CONTROL DIAGRAM

A device used to enhance power quality is the distributed power flow controller (DPFC). According to Fig. 5, it comprises of an a-shunt converter and a two-converter series converter. Voltage harmonic compensation is provided by a series converter, and current harmonic correction for load and microgrid is provided by a shunt converter. This inverter control diagram was created using a double loop of current controllers. In this instance, the inner loop contributes to the system's increased transient stability, while the outer loop also known as proportional resonant controllers helps to manage the steady-state error of the current comparator.

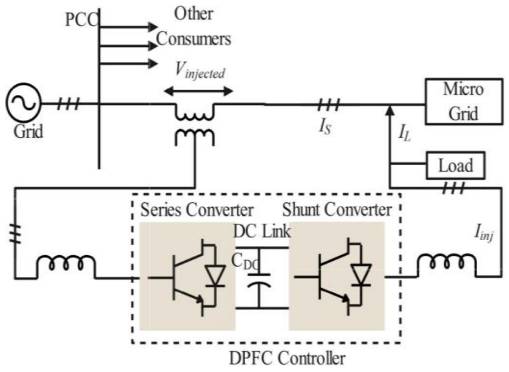

Fig.5. Designed DPFC controller block diagram.

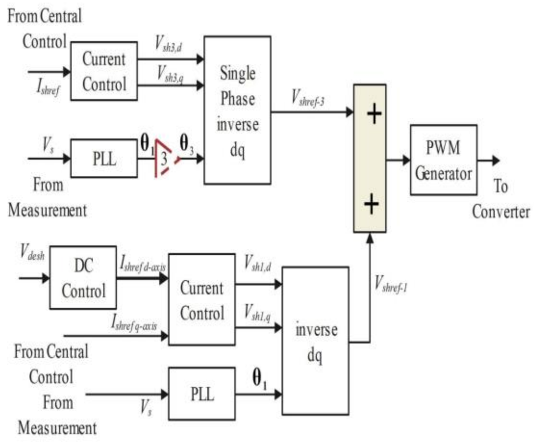

Fig.6. Designed DPFC control diagram.

Fig. 6 displays the converter control schematic. The load, system voltage, and current in this controller were all measured. These load currents underwent a conversion. The load, loss, and hybrid system power are used to create the grid active power. A grid power calculation was made using (2).

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

The reference current signal (i_{s1}^*) is determined from this computed power and applied to an inner current controller. To create the gate signals needed for the inverter, the supply current and reference current inner loops are compared in and applied to the hysteresis loop.

The DPFC terms are as follows:

1. DC link capacitance C_{DC} is 220 μF
2. DC link Voltage is 640 V
3. Carrier frequency is 2.08 KHZ

III. FUZZY LOGIC CONTROLLER

An entirely digital logic-based mathematical system called a fuzzy control system. In fuzzy logic, the controlling process can be carried out in four stages: fuzzification, membership function, rule-based creation, and defuzzification. In the process of fuzzification, the analogue input is transformed into fuzzy sets, and the input and output are expressed graphically using the membership function (i.e., triangular membership function). A rule-based formation can be used to express the relationship between the input and output. An if-then statement is used to explain the rules in this situation, as seen in Fig. 7.

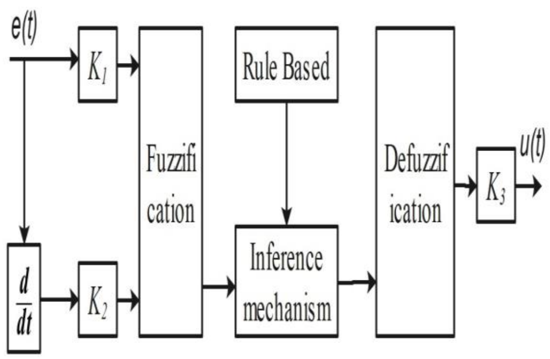

Fig.7. Fuzzy Logic based DPFC block diagram

The number of participants in the group determines the number of rules that are formed. Fuzzy logic's inputs connected to digital operators (AND or OR). Using the defuzzification procedure, the output of the fuzzy set is expressed as a crisp value. The centroid was picked as the defuzzification method in this instance.

IV. LION OPTIMIZATION TECHNIQUE

In this section, the proposed metaheuristic algorithm's inspiration is discussed, along with a thorough explanation of how it works. Male cubs stay with their birth pride until they are young adults, at which point they leave it and wander as itinerant lions. While travelling, a male encounter another pride, which may test the power of the pioneer. If the wandering guy is successful in this endeavour, it becomes a new source of pride. Every lion in the lion's calculation speaks to an answer. In Fig. 8, a stream chart of the LOA is shown. Four crucial advancements—pride age, mating, regional opposition, and regional takeover—continue this calculation.

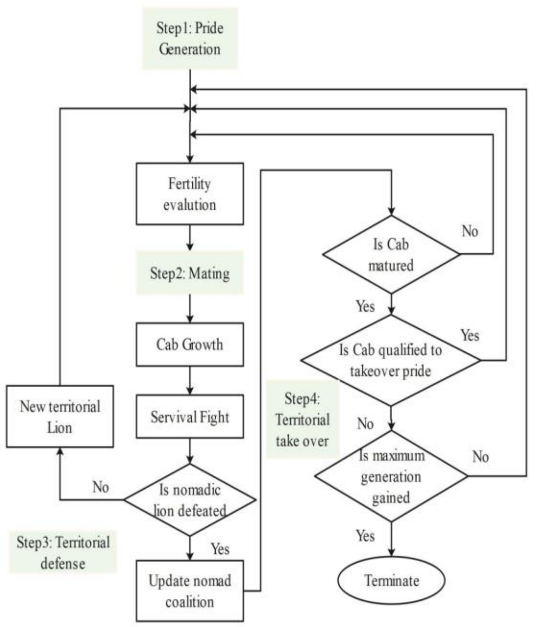

Fig.8. The designed LOA based DPFC Flow Structure.

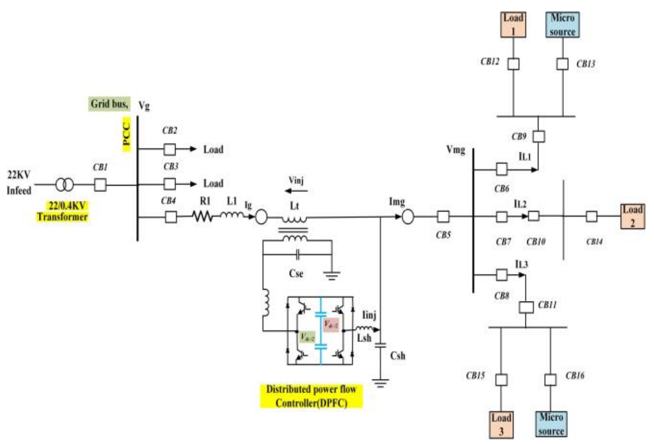

Fig.9. The designed MATLAB/Simulink System.

A. PRIDE GENERATION

Step one involves randomly assigning 2N lions to two male or female enterprises; the number of lions inside the resulting firms must be equal for both lions(L_1^{male},L_2^{male},….L_n^{male}) and lionesses (L_1^{female},L_2^{female},…,L_n^{female}). The pairing of a lion and a lioness result in the formation of n prides.

B. MATING

The technology of cubs uses functions called crossover and mutation that are quite similar to those found in genetic algorithms. In every satisfaction, the lion and lioness cross over twice to produce four pups. The resulting cubs then duplicate themselves once to produce any additional four cubs. Using k-manner clustering, the cubs are separated into male and female cubs. The number of male and female cubs in each pride was then tallied. In large institutions, vulnerable cubs are steadily eliminated in accordance with health popularity (goal function), so that the number of male and female cubs in each pride is often equal.

C. TERRITORIAL DEFENSE

This situation is similar to the satisfaction leader defending his position against an arbitrary intruder (Lnomad) before the satisfaction's cubs reach adulthood. The target function (the amount of time needed for the cubs to mature) is expressed by (3) - (6).

$$L^{pride} = \frac{1}{2(1+||L^{m\_cubs}||)}\{A + BC\} \quad (3)$$

Where,

$$A=F(L^{m})+F(L^{f}) \quad (4)$$

$$B= \frac{Age_{mat}}{age(cub)+1} \quad (5)$$

$$C=\sum_{C=1}^{||L^{m}cubs||} \frac{L_C^{m\_cubs}+L_C^{f\_cubs}}{||L^{m\_cubs}||} \quad (6)$$

V. SIMULATION MODEL AND RESULTS

In the MATLAB/SIMULINK environment, the LOA approach is built into the model of the framework depicted in Fig. 9. Two separate case studies were used to model and evaluate the proposed grid-interfaced hybrid system with a DPFC controller.

Solar system specifications are as follows:

1. Maximum Power is of 100W and voltage and current at maximum power is 18.7V and 5.35A respectively.
2. Open circuit voltage is 22.32V and short circuit current is 5.65A
3. No. Of panels and strings used are 10 and 1 respectively.
4. Cells of the string are 10 and the type of cell used is Poly Crystalline Silicon.

Wind turbine specifications are as follows:

1. Rated power output and peak power output are 5000W and 6800W respectively.
2. Rated voltage is 415V and cut-in speed, Nominal wind speed and cut-out-speed are 2, 8 and 18 rpm respectively.
3. Rated rotor speed is 250 rpm and generator efficiency is 0.95.
4. Noise level is <30db and no.of blades used are 3.
5. Material used for blade is glass fibre and type of generator used is SCIG.
6. Diameter of rotor is 3600 and C_p value at maximum is 0.18

A. CASE 1: ENHANCEMENT OF POWER QUALITY IN A HYBRID SYSTEM USING FUZZY AND LOAD-BASED DPFC CONTROLLERS

In this instance, a DPFC Fuzzy Controller is used to test the suggested system, and the experimental results are displayed in Fig. 10. Figure 10 illustrates the simulation outcome for non-linear grid voltage impacted by DG system circumstances and the injected voltage of DPFC. In Fig. 10, the simulation outcome for the grid's compensated output voltage is displayed.

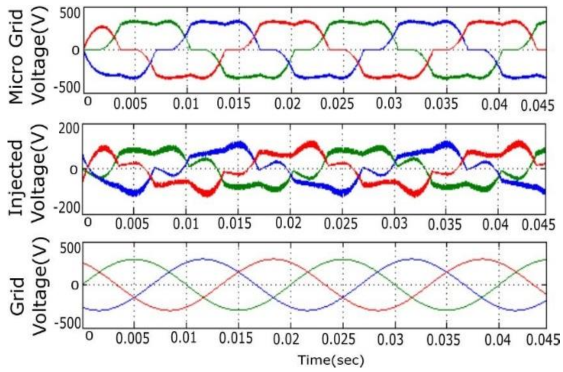

Fig.10. Output Waveforms for Injected voltage, adjusted micro grid voltage and distorted grid voltage.

In this instance, voltage distortions have an impact on the proposed grid-connected system, which helps to reduce the distortions created, and the adjusted voltage is monitored at the grid side.

Figure 11 depicts the injected current from the DPFC shunt converter at fundamental and third order frequencies along with the unbalanced current caused by the unbalanced load. The grid system's compensated current is displayed in Fig.11.

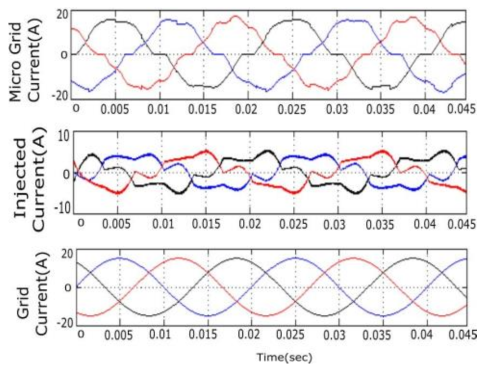

Fig.11. Output waveforms for injected current and adjusted grid current and uncompensated micro grid current

The suggested system is connected to both linear and unbalanced loads, which represent various load circumstances. The use of nonlinear loads causes imbalanced conditions that have an impact on the microgrid current. The shunt converter of the DPFC helps to alleviate these unbalanced conditions, and the compensated current is monitored on the grid side. A DPFC controller was used to correct the harmonic distortion of the grid current caused by the nonlinear and unstable loads. According to Figs. 12 and 13, and the comparison of THD in

Table 5, the THD for the grid current with the fuzzy-based DPFC controller was 3.92%, whereas that with the LOA-based DPFC controller was 3.12%.

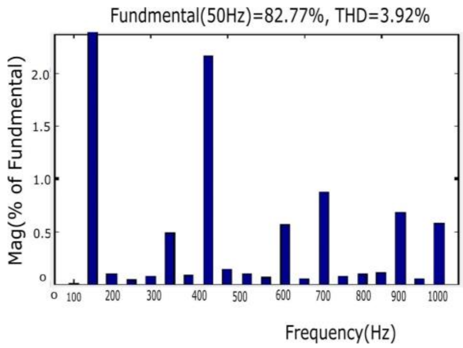

Fig.12. Harmonics distortion for grid current using fuzzy based DPFC

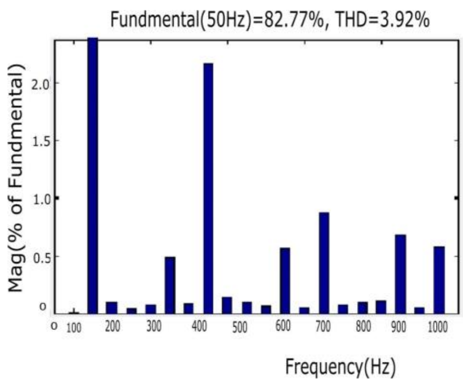

Fig.13. Harmonics distortion for grid current using LOA based DPFC.

Comparision of %THD under different controllers are listed as follows:

1. DPFC with PI controller optimization technique has 8.34%
2. DPFC with Fuzzy logic controller has 3.92%
3. DPFC with LOA technique has 3.12%

B.CASE2: ENHANCEMENT OF TRANSIENT STABILITY IN A HYBRID SYSTEM USING FUZZY AND LOAD-BASED DPFC CONTROLLERS

In order to increase the stability of the hybrid system, the proposed hybrid system converter control diagram was put to the test employing both fuzzy and LOA controllers. System parameter changes, load changes, or supply changes are the main reasons of stability issues. The stability of the generators' voltage, rotor speed, reactive power, and rotor angle were all tested using the simulation results presented in Figs. 14–17. Table 6 provides a comparison of rotor speed transient response and rotor angle transient response.

Comparative analysis for transient stability in terms of rotor angle and rotor speed settling are as follows:

1. DPFC with PI controller has 7.3 ms in terms of rotor angle and 7 ms in terms of rotor speed.
2. DPFC with fuzzy logic has 6.7 ms in terms of rotor angle and 6.5 ms in terms of rotor speed.
3. DPFC with LOA has 5.6 ms in terms of rotor angle and 5.5 ms in terms of rotor speed

Comparative analysis of % THD for different load levels are as follows:

Load 1: (4KW + 2kVar) ; Load 2:(5KW +3kVar)

1. DPFC with PI controller has 8.34% for load 1 and 10.57% for load2.
2. DPFC with fuzzy logic has 3.92% for load 1 and 5.46% for load 2.
3. DPFC with LOA has 3.12% for load 1 and 4.07% for load 2

Fig.14 displays the simulation findings for voltage transient stability variations brought on by changes in the load and system characteristics in a system connected to a microgrid. The designed DPFC series and shunt controllers are developed using various control strategies, including fuzzy and lion optimization controllers, to increase the stability conditions. The simulation outputs for the rotor angle deviations brought on by modifications in the resulting circumstances are shown in Fig.15. The designed DPFC series and shunt controllers were built with various control strategies, including fuzzy and lion optimization controllers, to increase the stability conditions.

The simulation findings for reactive power fluctuations brought on by various load scenarios in a microgrid-connected network are shown in Fig.16. To enhance the constancy conditions, the series and shunt controllers of the DPFC are constructed utilising various control approaches, those are fuzzy and lion optimization controllers. The simulation outputs for rotor speed distractions brought on by adjustments to the producing circumstances are shown in Fig. 17. To lessen the speed changes, the DPFC series and shunt controllers are applied using various control approaches, such as fuzzy and lion optimization controllers.

The hybrid system's planned DPFC controllers were controlled by a traditional PI controller, and the load current's THD was 8.34%. The hybrid system's controllers were tweaked utilising fuzzy logic and LOA controllers, and a comparison study was conducted between both methods in order to improve THD. The THD for any electrically engineered system must be less than 5% in accordance with IEEE 519-1992 standards. As a result, the fuzzy and LOA controllers' respective total harmonic distortions are 3.92% and 3.12%.

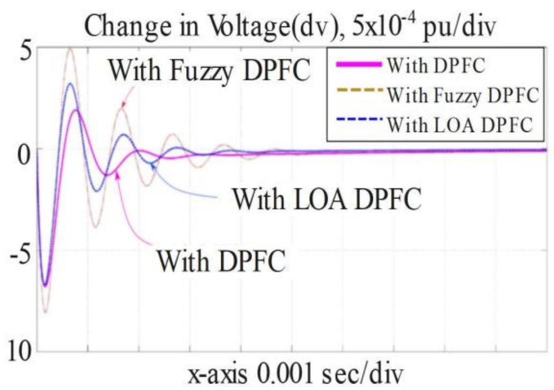

Fig.14. Simulation output for change in voltage with two controllers

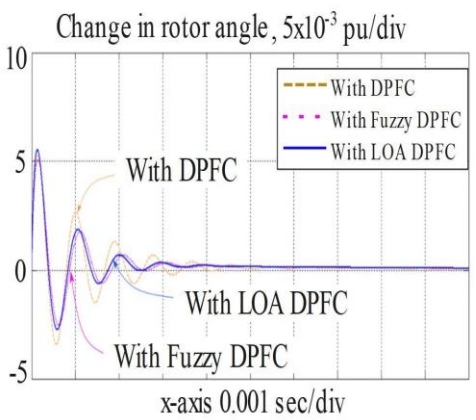

Fig.15. Simulation output for rotor angle with two controllers.

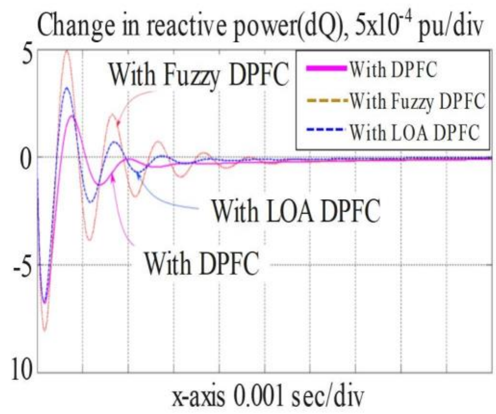

Fig.16. Simulation output for changes in reactive power with two controllers.

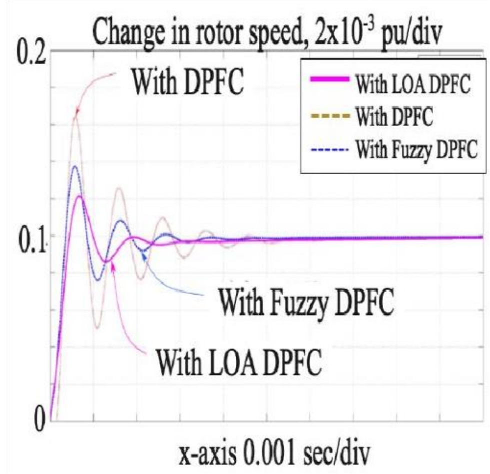

Fig.17. Simulation output for rotor speed under with two controllers.

VI. CONCLUSION

For a distributed power flow controller, this study suggests an optimization-based control technique to raise the hybrid system's reliability, power quality, and transient stability. In order to enhance the performance of the hybrid system, an MPPT controller was also added for the PV and wind energy systems. In the narration, many control strategies have been used to adjust the DPFC series and shunt controllers' parameters. The innovative optimization method for fine-tuning the DPFC's parameters is however proposed in this paper. Fuzzy logic control and a lion optimization method were used to fine-tune the DPFC's series and shunt controls in order to address power quality issues and enhance the voltage, reactive power, rotor speed and angle's transient stability. In Simulink/MATLAB environment, these examples passed testing and verification with flying colours. Based on these findings, the LOA-based controller outperformed the traditional fuzzy controller in terms of stability and power quality.

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