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Performance Improvement of Grid Interfaced Hybrid System Using Distributed Power Flow Controller Optimization Techniques

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ABSTRACT The main aim of this paper is to introduce a framework for the design and modelling of a photovoltaic (PV)-wind hybrid system and its control strategies. The purpose of these control techniques is to regulate continuous changes in the operational requirements of the hybrid system;currently, in power system networks, the distribution of energy plays a major role in maintaining power reliability in distribution systems. In this study, the proposed hybrid system was incorporated with a combined PV and wind energy system. Maximum power point tracking (MPPT) methods have been proposed to achieve maximum efficiency from the designed system. In addition, this study focused on improving the stability of the hybrid system. To improve the power quality and transient stability of the proposed system, we introduce a novel control strategy called the distributed power flow controller (DPFC) implementation with an optimization technique called the lion optimization algorithm(LOA)technique. This LOA control technique was developed for the first time in the application of a DPFC controller in a grid-connected system. The control technique was developed using signals from the system parameters, that is, voltage and current. To tune these parameters, this study used fuzzy logic and lion optimization techniques. The proposed system with controllers was tested in MATLAB/Simulink and the results were compared.

INDEX TERMS Distributed power flow controller, fuzzy logic controller, grid interconnected, lion optimization algorithm, PV system and wind energy system.

I. INTRODUCTION

In the present scenario, the demand for electrical energy has increased rapidly. The utilization of conventional power generation systems, such as gas, coal, and nuclear power plants, causes pollution and greenhouse effects [1]. To overcome these environmental problems and meet the electrical demands, non-conventional sources play a key role in the present energy generation systems [2]. The main advantages of these renewable sources are pollution free, low maintenance costs, and economical. There are more renewable systems available in the market; however, compared to all wind and solar energy systems, they play a key role because of their simple structure, available sources in the environment, and highly efficient conditions [3].

PV and wind energy systems play key roles as major energy sources in hybrid systems [4]. Photovoltaic systems are one of the most convenient renewable energy systems compared to other renewable energy sources [5]. Photovoltaic systems are not naturally stable in time, location, season, and weather, and the cost of installing solar systems is very high. Changes in weather conditions affect the output

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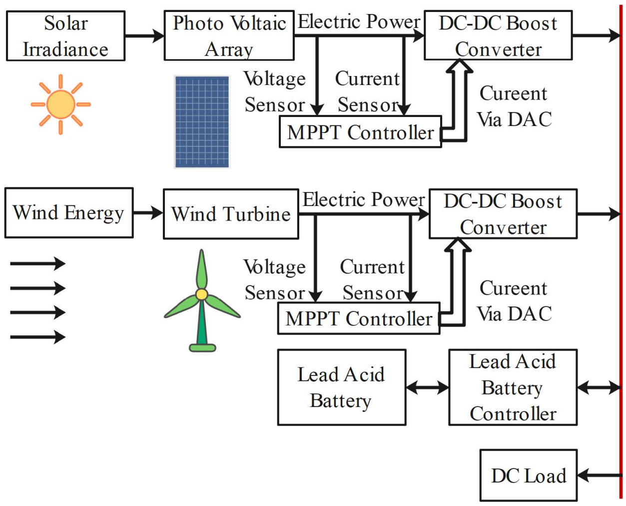

FIGURE 1. Structure of general microgrid system.

TABLE 1. DC-DC boost converter specifications.

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)	1500μF
IGBT	1200V/100A

generated by the solar system [6]. Therefore, to achieve the maximum output and increase the efficiency of the solar panel, MPPT techniques were implemented [7]. Based on the available natural conditions, wind energy systems are also a major renewable source for PV systems. The ratio of electrical energy generation is based on the availability of wind in nature [8]. Changes in weather conditions affect the outputs generated by the wind systems [9]. Therefore, to achieve maximum output and increase the efficiency of the wind system, MPPT techniques are implemented. The system must maintain synchronization with the grid. The solar system was connected to a voltage source inverter to match the frequency levels and system rates, and the control diagram for the inverter was designed using a general PWM technique, and the reference signals were chosen from the grid parameters [10]. Currently, electric power systems are large and complex. In an interconnected power framework, as a power burden request fluctuates arbitrarily, both territory recurrence and tie-line power exchange change. It is difficult to maintain harmony between age and burden without control [11]. Along these lines, a control framework is fundamental to drop the impacts of irregular burden changes and to maintain the recurrence at the standard worth and have demonstrated the basic idea of a restructured power system [12].

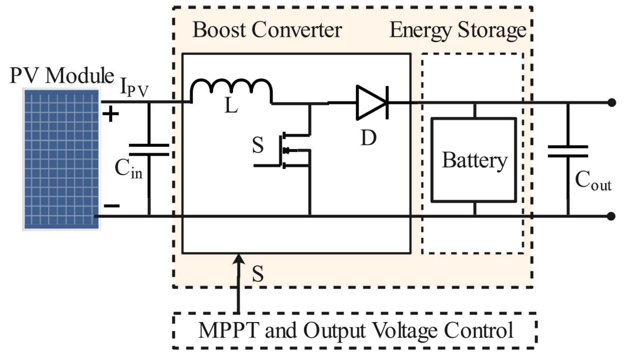

FIGURE 2. PV system with power converter.

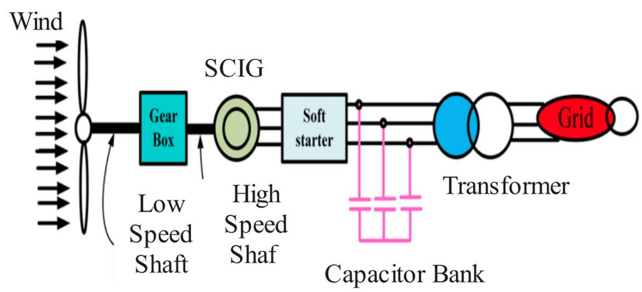

FIGURE 3. Basic diagram of SCIG wind turbine.

II. GRID INTERCONNECTED NETWORK

Fig. 1, shows a block diagram of a general micro grid system. A microgrid is a combination of photovoltaic and wind systems. Moreover, a bidirectional battery bank was used to improve the reliability of the power system. In this case, the PV, wind, and battery systems are interlinked at the DC bus, and these systems are interconnected with the grid system with the help of an inverter. The purpose of this inverter is to maintain synchronization between the grid and the hybrid system [13]. The proposed hybrid system was used to operate the different loads.

A. PV SOLAR SYSTEM

In the history of renewable energy, the solar energy system plays a key role out of all disturbed energy sources because of its availability in nature, reliability, and economy. Solar cells generate electrical energy from the photon effect of the sun irradiance. Initially, from solar cells, electric current flows later and is converted into PV voltage with the help of an equivalent electric circuit [14].The obtained DC voltage is varible with respect to solar irradiance, and temperature.To obtain a constant DC voltage from the solar system, an MPPT-based DC-DC boost converter is proposed, as shown in Fig. 2. The purpose of the MPPT is to track the maximum power from the solar [15]. These cells were arranged in series and parallel to meet the required voltage and current ratings. The parameters of boost converter specified in Table 1.

MPPT is based on tracking the instantaneous power of a PV system. The PV power was calculated using PV voltage and

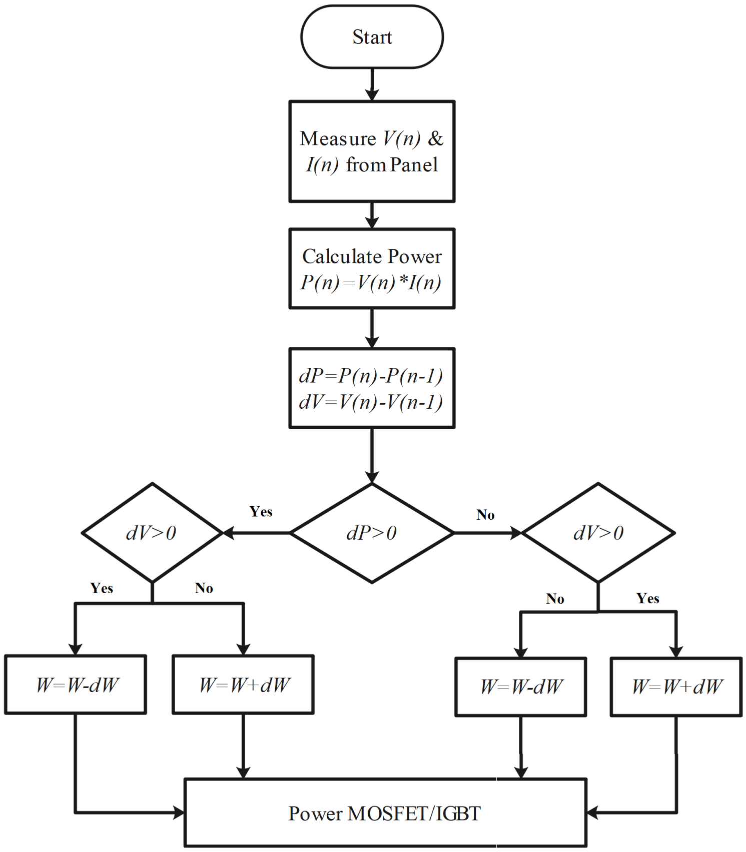

FIGURE 4. Flowchart representation of P&O technique.

TABLE 2. DPFC specifications.

Parameter Variable	Ratings
DC Link capacitor (C_{DC})	220 μF
DC Link voltage	640 V
Carrier Frequency	2.08 KHz

current. In this system, a P&O MPPT is proposed [16]. Voltage and current controllers are used to regulate the reference signals. A conventional PWM controller is used to generate the duty cycle required for the DC-DC converter from these reference signals [17].

B. WIND ENERGY SYSTEM

Wind turbines also play a key role in this disturbed energy system. Wind availability in nature, the energy conversion is performed in two stages:turbine blades convert wind speed to mechanical energy and later convert it to electrical energy with the help of an electrical generator [18].In addition, with these components, the wind turbine also consists of a gearbox mechanism to convert a low-speed shaft to a high-speed shaft [19]. In addition, a pitch angle controller was applied to rotate the wind blades according to the direction of the wind to improve reliability [20]. The speed of the wind reaching the

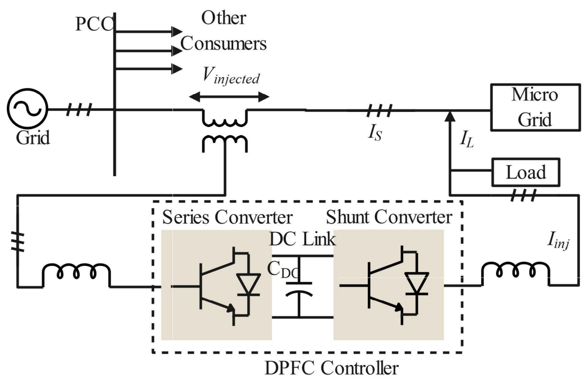

FIGURE 5. Proposed DPFC controller block diagram.

wind turbine was measured using a wind vane. The structure of a general wind turbine system with a conventional generator is shown in Fig. 3.The mathematical modelling of the wind energy system is expressed as the power generated by the wind turbine system, as expressed in (1).

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

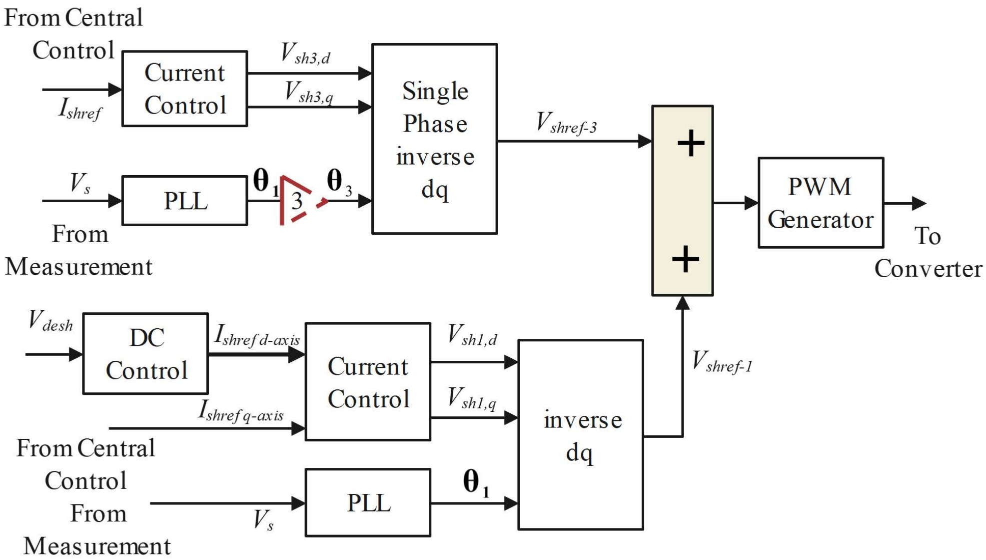

FIGURE 6. Proposed DPFC control diagram.

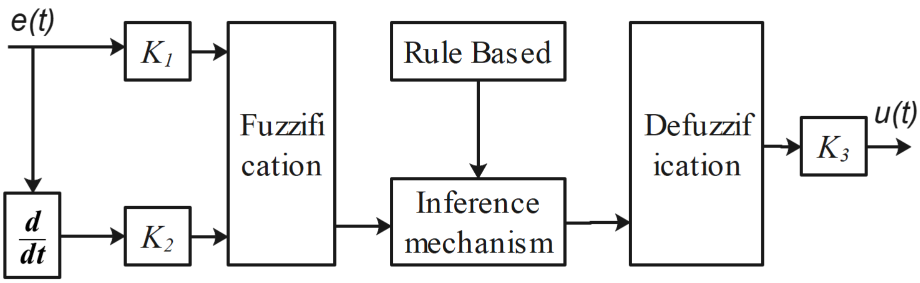

FIGURE 7. Fuzzy Logic based DPFC block diagram.

There are two types of generators available in the market: an induction generator and a synchronous generator [21]. In this case, a squirrel-type induction generator was used for the wind turbine to generate electrical energy [22]. An AC-DC-AC converter was used to achieve synchronization with the AC grid.

C. PERTURB AND OBSERVE MPPT ALGORITHM

Optimization problems are widely encountered in various fields of science and technology. Sometimes, such problems are very complex because of the actual and practical nature of the objective function or model constraints [23]. A typical optimization problem minimizes or maximizes an objective function subject to complex and nonlinear characteristics with heavy equality and/or equality constraints. In the perturb and observe method, the system tracks the changes in the array voltage and subsequently measures the change in the output power [24]. A flowchart of the P&O MPPT algorithm is shown in Fig. 4. In this flowchart, the voltage and current of the PV panel are measured, and the PV power is calculated [25]. The obtained PV power was measured using instantaneous PV power. From these results, the required reference current signal is measured. This loop was repeated continuously. The main disadvantage of this P&O technique is that it is not applicable to continuous changes in environmental conditions, such as irradiance and sunlight. The output is continuously compared with the previous output to obtain a better output.Owing to this complexity, the controller design is well suited for solving via optimization algorithms [26]. Electronic design via optimization algorithms is a well-established field of research and shows promise in providing an optimal solution for high-complexity design. In this study, the MPPT algorithm (perturb and observe) explains the maximum power tracking from the solar panels.

D. INVERTER CONTROL DIAGRAM

The distributed power flow controller (DPFC) is a power quality improvement device. It consists of a two-converter series converter and an a-shunt converter, as shown in Fig. 5. A series converter is used to provide voltage harmonic

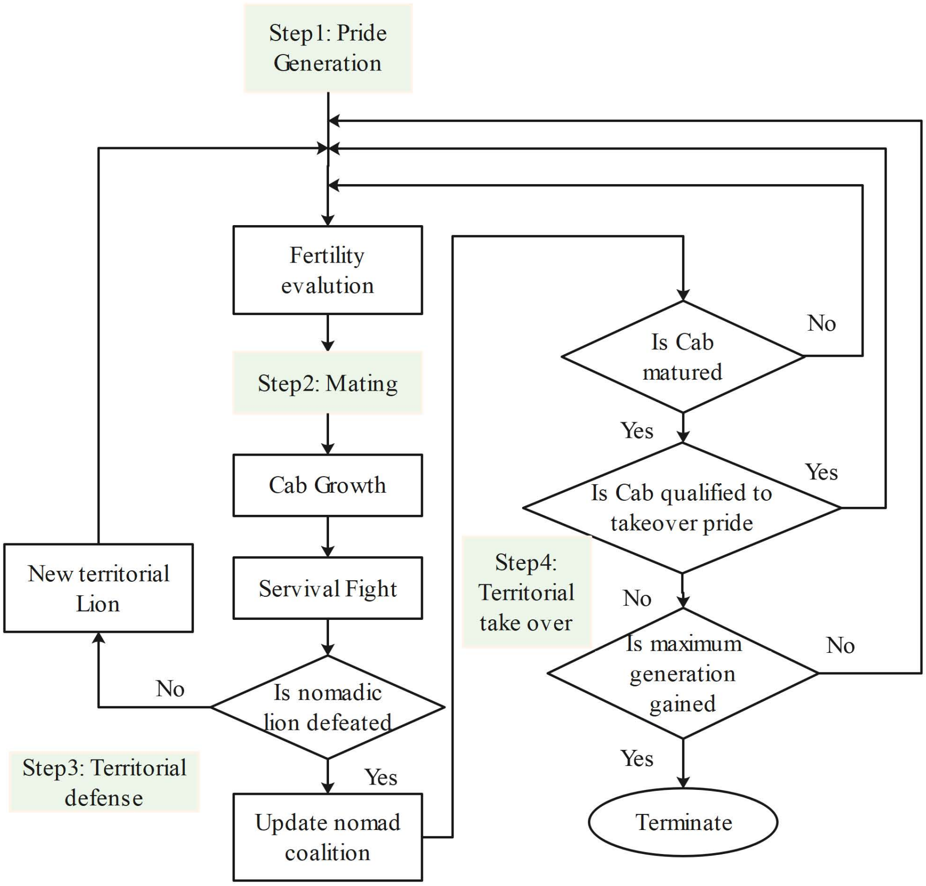

FIGURE 8. The flow structure of the proposed LOA based DPFC.

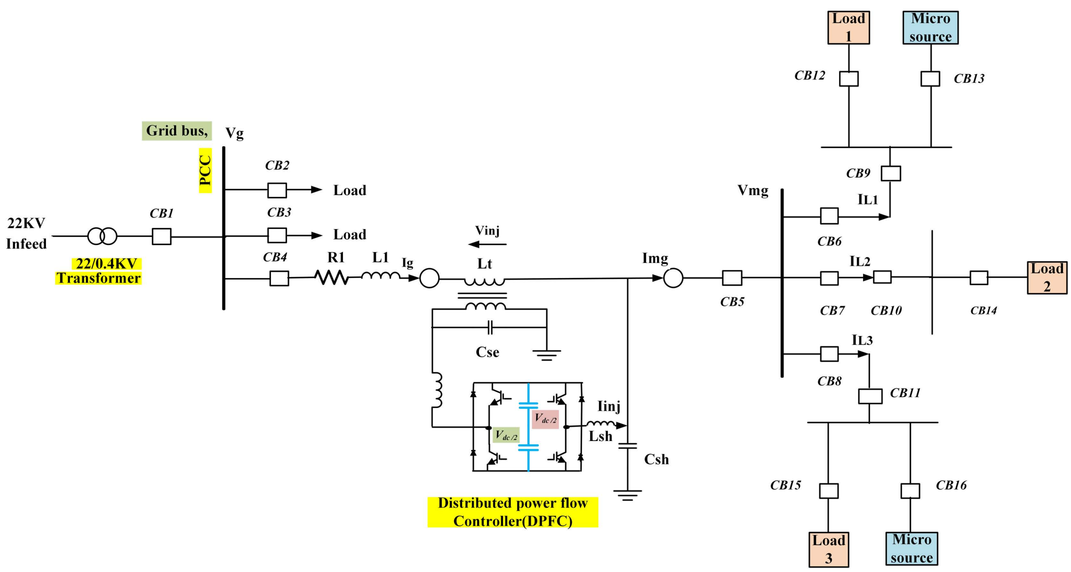

FIGURE 9. The proposed system in MATLAB/Simulink.

compensation, and a shunt converter is used for current harmonic compensation for the load and microgrid [27]. This inverter control diagram was designed based on the current controllers in a double loop. In this case, the outer loop, called proportional resonant controllers, helps to regulate the steady-state error of the current comparator, and

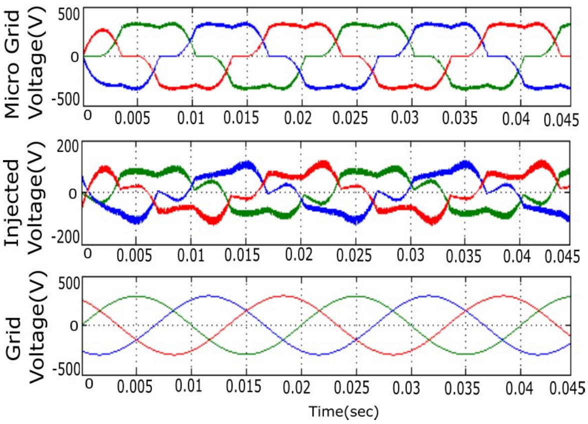

FIGURE 10. Output waveforms for distorted micro grid voltage, injected voltage, and compensated grid voltage.

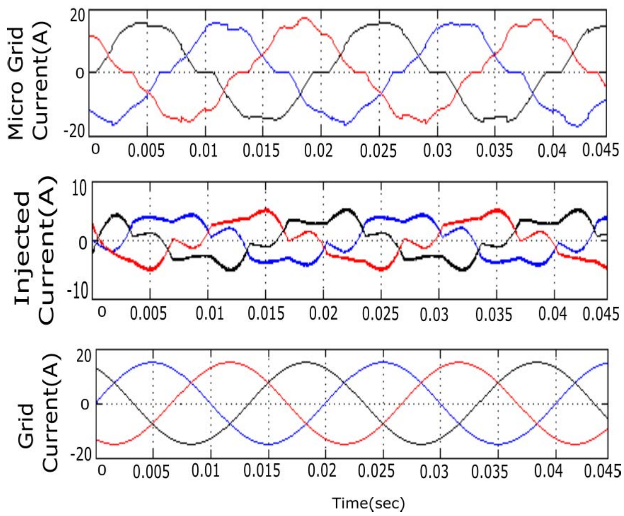

FIGURE 11. Output waveforms for uncompensated micro grid current, injected current, and compensated grid current.

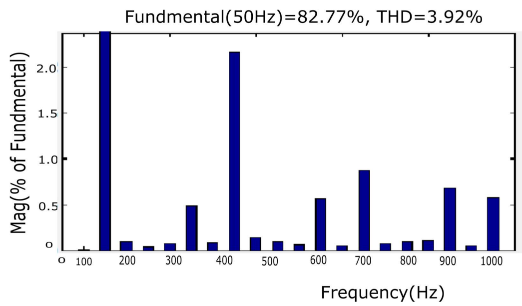

FIGURE 12. Total harmonics distortion for grid current using fuzzy based DPFC.

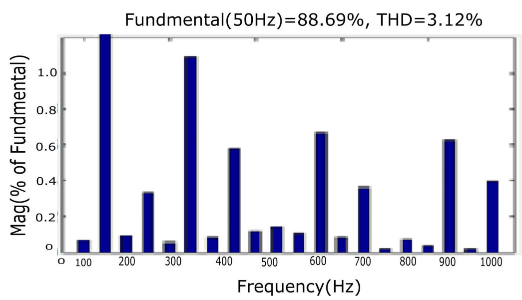

FIGURE 13. Total harmonics distortion for grid current using LOA based DPFC.

the inner loop helps to improve the transient stability of the system [28]. The converter control diagram is shown in Fig. 6.In this controller, the load, system voltage, and current were measured. These load currents were converted to a d-q transformation using Park's technique [29]. The grid active power is obtained from the load, loss, and hybrid system power. The grid power was calculated using (2).

$$P_g = P_L + P_{SL} - P_{PV} \tag{2}$$

From this calculated power, the reference current signal (i_{s1}^*) is identified and applied to an inner current controller. In, the inner loop of the reference current is compared with the supply current and applied to the hysteresis loop to generate the gate signals required for the inverter. The parameters of the DPFC are specified in Table 2.

III. FUZZY LOGIC CONTROLLER

A fuzzy control system is a mathematical system that is completely based on digital logic. The controlling process can be performed in four stages in fuzzy logic:a) fuzzification, b) membership function, c) rule-based formation, and d) defuzzification [30].In fuzzification, the analog input is converted to fuzzy sets, and the input and output are expressed in a graphical representation under the membership function (i.e.,triangular membership function).The relation between the input and output can be expressed as a rule-based formation [31].In this case, the rules are expressed using an if-then statement, as shown in Fig.7. The number of rules formed depends on the number of memberships in the inputs of fuzzy logic, which are related to digital operators (AND or OR). The output obtained from the fuzzy set is expressed as a crisp value using the defuzzification process. In this case, the centroid was chosen as the defuzzification method [32].

IV. LION OPTIMIZATION TECHNIQUE

This section describes the inspiration for the proposed metaheuristic algorithm, and the process is explained in detail. Male cubs live in their birth to the world pride until they arrive at early adulthood, whereupon they disregard the pride to meander as itinerant lions,during which a roaming male experiences another pride, which might challenge the pioneer for strength [33]. If the itinerant male succeeds in this experience, it turns into a new pioneer of pride. In the lion's calculation, every lion speaks to an answer. A stream chart of the LOA is presented in Fig.8.This calculation continues through four essential advances: pride age, mating, regional resistance and regional takeover [34].

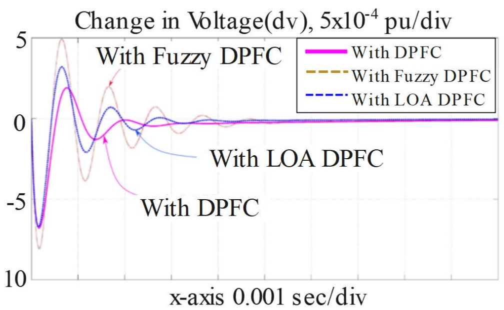

FIGURE 14. Simulation result for change in voltage under two controllers.

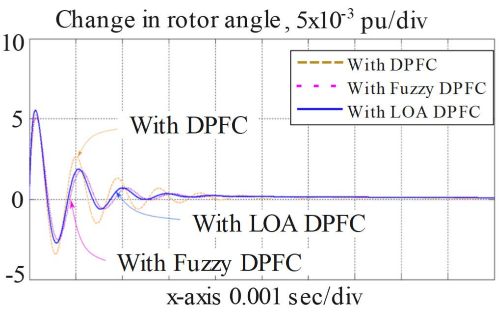

FIGURE 15. Simulation result for rotor angle under two controllers.

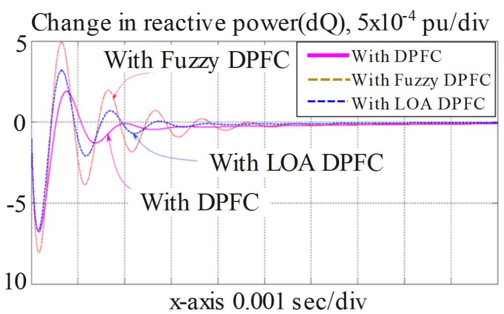

FIGURE 16. Simulation result for changes in reactive power under two controllers.

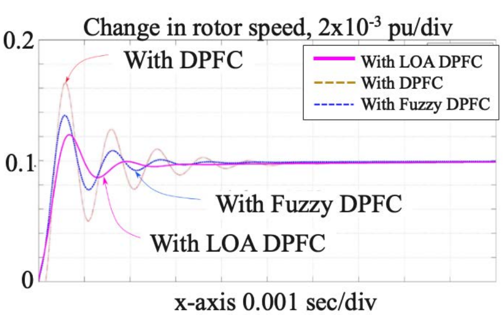

FIGURE 17. Simulation result for rotor speed under two controllers.

A. PRIDE GENERATION

In step one, $2N$ lions are randomly assigned to two male or female businesses,and the number of lions inside the ensuing companies must be equal, lion (L_1^{male}, L_2^{male},..., L_n^{male}) and lionesses (L_1^{female}, L_2^{female},..., L_n^{female}). A lion and a lioness are then paired as a delight, ensuing in n prides.

TABLE 3. System parameters for PV system.

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	1
Cells in string	10
Type of cell	Poly crystalline silicon

TABLE 4. Specifications of wind turbine.

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
C_p value at max	0.18

TABLE 5. Comparative analysis for THD under different controllers.

Controller	Optimization Technique	%THD
DPFC	PI controller	8.34
DPFC	Fuzzy logic	3.92
DPFC	LOA	3.12

B. MATING

Crossover and mutation functions much like the ones used in genetic algorithms are used for the technology of cubs.To start with, the lion and lioness in every satisfaction crossover two times to generate four cubs ($L_{(1-4)}^{cubs}$).The resulting cubs then replica once to generate any other four cubs ($L_{(5-8)}^{cubs}$).

TABLE 6. Comparative analysis for rotor angle transient response.

Controller	Optimization Technique	Transient Stability (in-terms of change in Rotor Angle) Settling Time (ms)	Transient Stability (in-terms of change in Rotor Speed) Settling Time (ms)
DPFC	PI controller	7.3ms	7 ms
DPFC	Fuzzy logic	6.7ms	6.5 ms
DPFC	LOA	5.6ms	5.5 ms

TABLE 7. Comparative analysis for total harmonic distortion between different controllers.

Controller	Optimization Technique	%THD Load 1: (4 kW+2 kVar)	%THD Load 2: (5 kW+3 kVar)
DPFC	PI controller	8.34	10.57
DPFC	Fuzzy logic	3.92	5.46
DPFC	LOA	3.12	4.07

The cubs are divided into male cubs (L_{male}^{cubs}) and female cubs (L_{female}^{cubs}) using k-manner clustering.We then counted the number of male and female cubs in each pride [35]. Vulnerable cubs in large institutions are steadily killed in steps with health popularity (target function), such that the variety of male cubs is usually the same as the variety of female cubs in every pride.

C. TERRITORIAL DEFENSE

This case mimics the satisfaction chief protecting his function in opposition to a random interloper (Lnomad)earlier than the cubs in the satisfaction reach adulthood.The time required for the cubs to reach adulthood (the target function) is expressed by (3)-(6).

$$L^{pride} = \frac{1}{2\left(1+\left|\left|L^{m-cubs}\right|\right|\right)}\{A+BC\} \tag{3}$$

where,

$$A = F\left(L^{m}\right)+F\left(L^{f}\right) \tag{4}$$

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

$$C = \sum_{C=1}^{\left|\left|L^{m-cubs}\right|\right|} \frac{L_C^{m-cubs}+L_C^{f-cubs}}{\left|\left|L^{m-cubs}\right|\right|} \tag{6}$$

V. SIMULATION MODEL AND RESULTS

The model of the framework shown in Fig.9 is created in the MATLAB/SIMULINK condition, and the LOA technique is composed. The proposed grid-interfaced hybrid system with a DPFC controller was modelled and tested in two different case studies. The parameters of the solar-wind hybrid system are listed in Tables 3 and 4.

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

In this case, the proposed system is tested with a DPFC-fuzzy controller, and the experimental results are shown in the Fig. 10. The simulation result for non-linear grid voltage affected by DG system conditions, and the injected voltage of DPFC is shown in Fig.10.The simulation result for compensated output voltage of grid is shown in Fig.10. In this case, the proposed grid-connected system is affected by voltage distortions, which helps mitigate the distortions caused,and the compensated voltage is measured at the grid side. The unbalanced current affected by the unbalanced load is shown in Fig.11, and the injected current from the DPFC shunt converter under fundamental and 3^{rd} order frequencies is shown in Fig.11.The compensated current in the grid system is shown in Fig.11.The proposed system is connected to different load conditions, that is, linear and unbalanced loads. Owing to the utilization of nonlinear loads, the microgrid current is affected by unbalanced conditions, the shunt converter of the DPFC helps to mitigate the unbalanced conditions, and the compensated current is measured at the grid side.The harmonic distortion of the grid current affected by the non-linear and unbalanced loads was compensated using a DPFC controller. The THD for the grid current with the fuzzy-based DPFC controller was 3.92%, while that with the LOA-based DPFC controller was 3.12%, as shown in Fig.12 and 13, and the comparison of THD shown in Table 5.

B. CASE 2: IMPROVEMENT OF TRANSIENT STABILITY IN A HYBRID SYSTEM USING FUZZY AND LOA-BASED DPFC CONTROLLERS

In this case, the proposed hybrid system converter control diagram was tested using both fuzzy and LOA controllers to improve the stability of the hybrid system. The main causes of stability problems are changes in system parameters, load changes, or changes in supply. The simulation results shown in Fig. 14-17 were measured to observe the stability in voltage, rotor speed, reactive power, and rotor angle of the generators, respectively.A comparative analysis for rotor angle transient response and rotor speed transient response is presented in Table 6. A comparative analysis of the THD of the grid current under different load conditions is presented in Table 7. Fig.14 shows the simulation results for voltage transient stability changes in a microgrid-connected system caused by changes in load and system parameters.To improve the stability conditions, the proposed DPFC series and shunt controllers are implemented using different control techniques,such as fuzzy and lion optimization controllers. Fig.15 shows the simulation results for the rotor angle deviations caused by changes in the generating conditions. To improve the stability conditions, the proposed DPFC series and shunt controllers were implemented using different control techniques, such as fuzzy and lion optimization controllers. Fig.16 shows the simulation results for the reactive power changes in a microgrid-connected system caused by different load conditions. The series and shunt controllers of the DPFC are implemented using different control techniques, such as fuzzy and lion optimization controllers, to improve the stability conditions. Fig.17 shows the simulation results for the rotor speed deviations caused by changes in the generating conditions. The DPFC series and shunt controllers are implemented with different control techniques, such as fuzzy and lion optimization controllers, to reduce the speed changes.The proposed DPFC controllers implemented in the hybrid system were regulated using a conventional PI controller, and the THD of the load current was 8.34%.To obtain better THD, the controllers of the hybrid system were tuned using fuzzy logic and LOA controllers, and a comparative analysis was performed between these techniques. According to IEEE 519-1992 standards the THD for any electrically designed system must be less than 5%. Thus, the total harmonic distortions obtained by the fuzzy and LOA controllers are 3.92% and 3.12%, respectively.

VI. CONCLUSION

This study proposes an optimization-based control strategy for a distributed power flow controller to improve the reliability, power quality, and transient stability of a hybrid system. In addition, an MPPT controller was implemented for both the PV and wind energy systems to improve the performance of the hybrid system. In the literature, different control techniques have been applied to tune the parameters of DPFC series and shunt controllers. However,this study proposes a novel optimization technique for tuning the parameters of the DPFC. The series and shunt controls of the DPFC were tuned using fuzzy logic control and a lion optimization algorithm to improve the power quality problems and the transient stability of the voltage, reactive power, rotor speed,and angle. These cases were successfully tested and verified in the MATLAB/Simulink environment.Based on these results, improvements in stability and power quality were achieved with the LOA-based controller as compared to the conventional fuzzy controller.

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