Efficient power system operation through fuzzy and PSO algorithm for power loss reductions and voltage profile improvement by optimal placement of D-STATCOM

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Abstract: This research aims to enhance voltage profiles and minimize power losses. in power systems through the strategic use of Distribution Static Compensators (DSTATCOM). Fuzzy Logic and Particle Swarm Optimization (PSO) work in concert to enhance the optimization process. Using a thorough testing framework, the paper assesses the suggested methodology on two different power system models, comprising 33 and 69 buses. Normal operating conditions and variations at 125%, 150%, and 175% of the nominal load are included in the testing scenarios. This rigorous testing regimen offers a comprehensive evaluation of the algorithm's performance and robustness under various operating scenarios. The purpose of placing the DSTATCOM devices strategically inside the electrical grid is to decrease power losses and enhance system voltage profiles. Uncertain. While the PSO algorithm maximizes the effectiveness of DSTATCOM unit placement, logic is used to tackle the inherent uncertainties and imprecisions in the power system. Under varied load conditions, this work demonstrates a major improvement in voltage profiles and a large reduction in power losses.

1 Introduction

The goal of efficiency, dependability, and sustainability is still crucial in the dynamic world of power systems. The proper operation of power distribution networks is becoming increasingly important as societies continue to rely on electricity as a cornerstone for development. Reducing power losses and increasing voltage profiles are two critical areas of power system management that are the focus of this research. Power interruptions in distribution cause environmental problems in addition to financial inefficiencies. Similarly, it's critical to maintain a steady and ideal voltage profile to guarantee the smooth operation of electrical gear and appliances. The implementation of cutting-edge technologies is crucial in this situation, and Distribution Static Compensators (D STATCOM) is one of the main players in the race for better power system performance.

This study attempts to determine the best way to strategically place DSTATCOM devices with regard to minimize power loss and improve voltage profile. Finding these compensators at the network's most advantageous locations is a difficult task, though. Power systems are dynamic and complicated, making traditional approaches inadequate to handle their needs. Therefore, modern optimization techniques must be integrated.

To address these issues, the study suggests a novel strategy that blends fuzzy logic and the Particle Swarm Optimization method. With regard to modeling and controlling decision-making processes, fuzzy logic offers a solid framework that takes into account the inherent uncertainties in power systems. Simultaneously, the PSO algorithm provides an effective way to search the large solution space and find ideal placement configurations. It draws inspiration from group behaviors observed in nature. The goal of this research is to support current efforts to convert power systems into extremely efficient, dependable, and adaptive networks by combining the strengths of PSO with fuzzy logic in a synergistic way. The upcoming sections will address the theoretical foundations, methodology, and empirical findings in details. They

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will also offer insights into the possible uses of this integrated approach for the long-term, sustainable enhancement of power system operations.

2 Literature Survey

[1] The study recommends a hybrid energy storage system for a DC microgrid that is based on PI controllers and was created using the PSO approach in order to effectively utilize renewable electricity. [2] This study recommends a hybrid energy storage system for a DC micro grid that is based on PI controllers and was created using the PSO technique to effectively use renewable electricity. [3] The study utilized a backward/forward sweep load analysis and PSO algorithm to identify the optimal bus voltage magnitude in a 15 kV system with low voltage stability issues. [4] The distribution static compensator (DSTATCOM) placement and sizing method in radial distribution networks is optimized using a multi-objective approach that takes power loss reduction, voltage profile enhancement, and network reliability into account. The technique maximizes the location and size of DSTATCOMs and has been verified on the IEEE 33-a bus and the Ahvaz 59-bus network. [5] Using an IEEE 69 bus system for rural electrification in India, a novel method for reducing power losses and improving voltage profile in distribution networks is given and evaluated in this study. [6] The paper introduced a particle swam methodology for optimizing nonlinear functions and discusses its evolution, implementation, benchmark testing, applications, and its relationships with artificial life and genetic algorithms. [7] The paper investigated the best D-STATCOM allocation for redial distribution systems, with an emphasis on energy conservation, voltage profile improvement, and power loss reduction.

Determining the ideal D-STATCOM size, researching different load scenarios, and contrasting voltage levels are important contributions. A radial distribution network using IEEE 33 bus traffic is used to test the technique. [8] The approach for locating DSTATCOMs in radial distribution systems that minimize losses and improve voltage profiles was provided in the paper. The algorithm's performance was evaluated on a 33-bus system. [9] The study compares IEEE 33-bus and IEEE 69-bus radial distribution systems in two distinct scenarios to investigate the placement and sizing of Distributed Generation (DG) in distribution networks utilizing Particle Swam Optimization techniques. [10] To tackle unknown circumstances, the study suggests probabilistic approaches for effective D-STATCOM allocation.

It reduces power losses, boosts the voltage deviation index, and lowers installation costs. To apply the Latin hypercube sampling method and k-means -based data clustering strategy, an IEEE 69 node test network is used. [11] This research suggests a useful network architectural technique that assigns D-STATCOM, DG units, and EVCSs in addition to network reconfiguration to maximize the utilization of radial distribution systems (RDSs). DG, D-STATCOM, and EVCS allocation in RDS and network reconfiguration are solved by the binary bat algorithm (BBA), which has been tested on IEEE 33 bus RDS.

3 Modelling of D-STATCOM

Encapsulating inside a power framework, the electrical characteristics and behaviour of a Distribution Static Compensator (DSTATCOM), as illustrated in Figure 1. A useful instrument for reactive power support, power factor enhancement, and voltage sag and surge prevention is DSTATCOM.

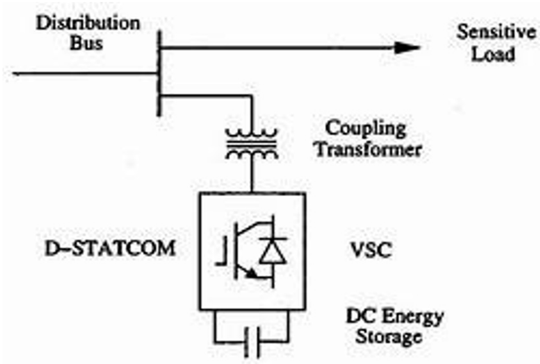

Fig: 1 DSTATCOM single-line diagram

4 D STATCOM Components

Voltage Source Inverter (VSI): DSTATCOM typically includes a VSI as its main power electronics component. The VSI is responsible for generating the required compensating current.

DC Capacitor: The DC capacitor modifies the DC voltage applied to the VSI by acting as an energy storage component.

Controller: The D STATCOM's control system is essential to controlling its operation. It creates the proper control signals for the VSI while keeping an eye on the system characteristics.

Problem formulation: The suggested approach's primary goal is to lower distribution system power losses. The overall power loss in a distribution system with 'b' branches is calculated using.

$$P_{LT}=\sum_{i=1}^{b} I_i^2 R_i \qquad (1)$$

where R is the network's I th branch's resistance and I is the current of the Branch. The total losses incurred by the active and reactive parts are expressed as,

$$P_{LA}=\sum_{i=1}^{b} I_{ai}^2 R_i \qquad (2)$$

$$P_{LR}=\sum_{i=1}^{b} I_{ri}^2 R_i \qquad (3)$$

The losses PLR connected to the branch current's reactive component and PLA connected to its active component, for a specific single source radial distribution network topology. To offer a local power supply, DSTATCOM can be positioned to minimize losses and improve the voltage profile. By using an optimally sized DSTATCOM, the PLA, and PLR related to the real and reactive components of branch current can be decreased

5 Fuzzy logic controller

Principal goals should be taken into account when creating a fuzzy logic to determine where DSTATCOM should be placed,

Reducing the amount of power outage and Keeping the voltage within allowable bounds.

The DSTATCOM placement suitability of each node in the distribution system is then evaluated using a fuzzy inference system (FIS) that follows a set of criteria. In the first phase, the real and reactive power losses must be computed using the load flow solution for the original system. All over again to minimize power loss, load flow solutions are required to offset the total reactive loads at each distribution system node.

The loss reductions are then linearly normalized in the [0, 1] range, with 0 being the lowest loss reduction and 1 representing the largest. The following formula can be used to determine the power loss index value for the nth node.

$$PL(n) = \frac{LR(n)-LR(min)}{LR(max.)-L\ \ (min)} \quad (4)$$

The input variables are the Power Loss Index (PLI) plus the nodal voltages (V) per unit. The output variable is the DSTATCOM Suitability Index (DSTATCOM-SI). The Per Unit nodal voltage varied in between 0.9 to 1.1, and the PLI range is zero to one. The output variable DSTATCOM SI has a range of zero to one. 5 triangle membership functions have been chosen for PLI. Those are L, LM, M, HM, and H. All 5 of the membership features are revealed here.

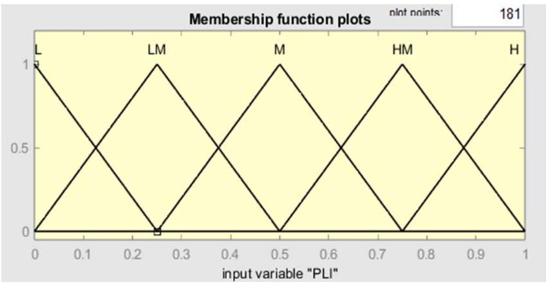

Fig:2 PLI Membership functions

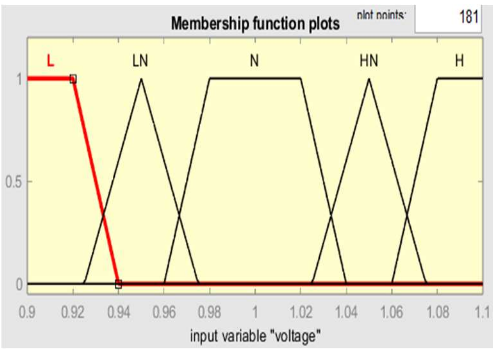

Fig:3 Membership functions for voltage

For voltage, five membership functions have been chosen. L, LM, M, HM, and H are those. As seen in Fig. 3, these membership functions are triangular and trapezoidal. For DSTATCOM-SI, five triangle membership functions have been chosen. L, LM, M, HM, and H are those. The following 5 membership rules are

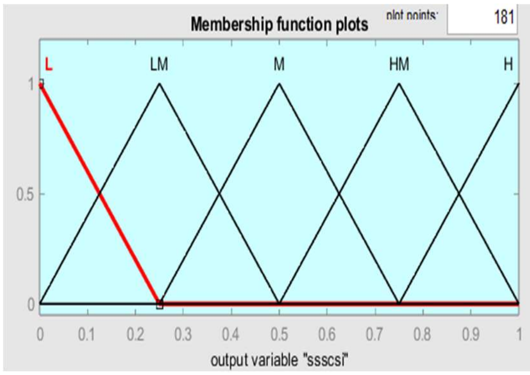

Fig:4 Membership functions for SSSCSI

To determine where in Fuzzy a node is best suited for DSTATCOM installation, rules must be created to evaluate that node's appropriateness. Table of fuzzy rules as displayed in the table1

Table 1: Rules table for FLC design

AND		VOLTAGE L	LM	M	HM	H
PLI	L	LM	LM	L	L	L
	LM	M	LM	LM	L	L
	M	HM	M	LM	L	L

The rules are in the following format:

- If voltage is L and PLI is H, then DGSI is H.
- When voltage is N and PLI is M, DGSI is LM.
- When voltage is H and PLI is H, DGSI is LM.

In this context, the "if" and "then" portions of a rule are referred to as rule-antecedent and rule-consequent, respectively. Twenty-five rules have been derived for two inputs and five membership functions.

5.1 Particle Swarm Optimization

Particle swarm optimization, or is a population-based optimization technique that was developed after studying the social behaviors of fish and birds. Created in 1995 by Kennedy and Eberhart, PSO iteratively updates a population of viable solutions, or particles, based on their individual and collective experiences to determine the optimal solution for a given problem. Let X and V stand for the particle's position and velocity, respectively. The particles' objective is to use the following formulas to get the best particle possible. By utilizing the following formulas to update the location and velocity in a swarm, we can determine the global best position (gbest) and the personal best position (pbest). The velocity update equation is as follows.

$$V^{k+1}=WV_I^k+C_1rand_1(pbest_i - X_i)$$
$$+C_2rand_2(gbest_i - X_i) \quad (5)$$

Particle update equation is as follows

$$X_i^{k+1} = X_i^k + V_I^{k+1} \quad (6)$$

The Weight update equation is as

$$W = w_{max} - ((w_{max} - w_{min}) * t)/T \quad (7)$$

Considered constraints are as follows

$$V_i^{\min} \le V_i \le V_i^{\max}$$

$$X_i^{\min} \le X_i \le X_i^{\max}$$

5.2 PSO Algorithm Steps

Step: 1 Initialization:

Spread out a swarm of particles across the solution space at random places and velocities.

Step: 2 Assessments

Examine the fitness or objective function value of each particle.

Step: 3 Revise g_{best} and p_{best}:

Update the particle's personal best if its fitness in its present location increases. Update the global best based on the best particle in the entire swarm.

Step: 4 Update Velocities and Position:

Modernize the position and velocity of each particle, considering both the global and personal bests, using the PSO equations.

Step: 5 Iterate:

Proceed with steps 2-4 until one of the requirements for termination (such as reaching a maximum number of iterations or finding a practical solution) is met. The flowchart of the PSO algorithm is shown in Fig. 5.

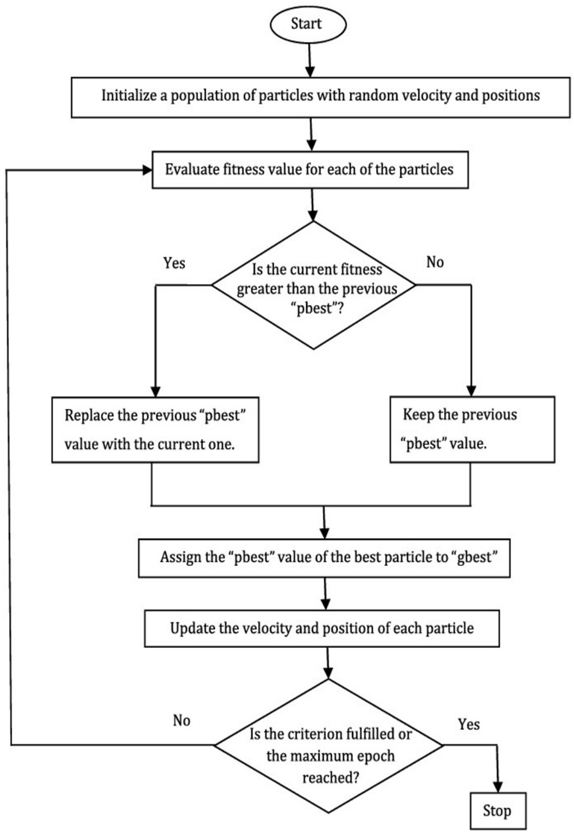

Fig: 5 PSO algorithm Flowchart

6 Results and Discussions

It is coded and run in the MATLAB/Simulink environment on the common 33- and 69-buses.

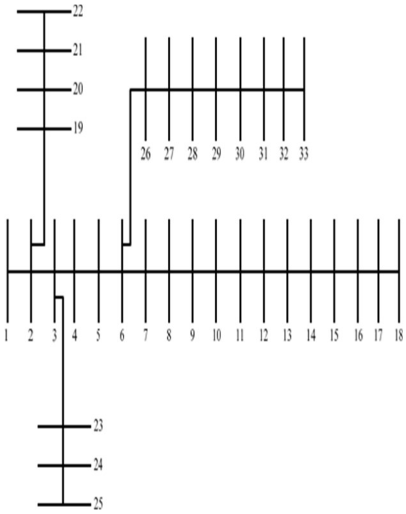

Fig.6 Sample 33- bus test system

By employing suggested fuzzy and PSO algorithms to get maximum power loss reduction and voltage augmentation, the 33-bus test system optimally positions DSTATCOM at buses under a variety of load conditions.

The table below shows the results for an IEEE 33-bus system under various % load scenarios.

Table: 2 Results for IEEE 33-bus system

loading Condition	Losses without device (kW)	Location of device	PSO	
			Size of device (kVAr)	Losses with device in(kW)
Normal	202.766	30	1253.2	143.64
125%	329.998	30	1576.8	231.08
150%	496.565	30	1905.5	343.16
175%	709.021	29	2354.3	488.63

Table 2 shows that, under typical loading conditions, the 33-bus system's total losses without a device are 202.7661 kW. Once the device is positioned at the 30th bus, the losses are reduced to 143.6445 kW and a device of 1253.2 kVAr is needed to achieve this reduction in losses. The overall losses at the 33-bus system device under 125% loading conditions are 329.998 kW and the losses are reduced to 231.0839 kW once the device is placed at the 30th bus and this reduction in losses necessitates a device size of 1576.8 kVAr.

The 496.5653 kW is the total losses that occurred at the 33-bus system device at 150% loading conditions. The losses are reduced to 343.1695 kW once the device is placed at the 30th bus; this reduction in losses necessitates a device size of 1905.5 kVAr. The 33-bus system's total losses without a device under 175% loading conditions are 709.0218 kW. The losses are reduced to 488.6277 kW after the device is placed at the

29th bus; this reduction in losses necessitates a device size of 2354.3 kVAr.

A graphical illustration of the 33-bus system under various load scenarios is shown in Fig. 7.

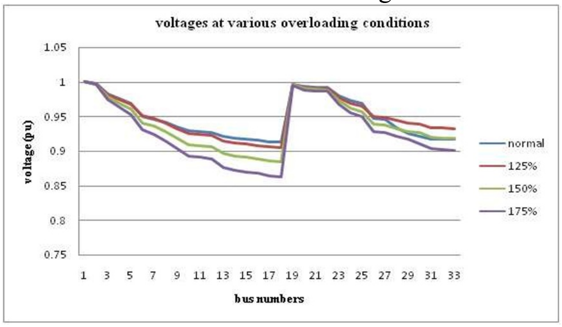

Fig. 7: A graphic depiction of the 33-bus system under different loading conditions

Test system 2: IEEE 69-bus system

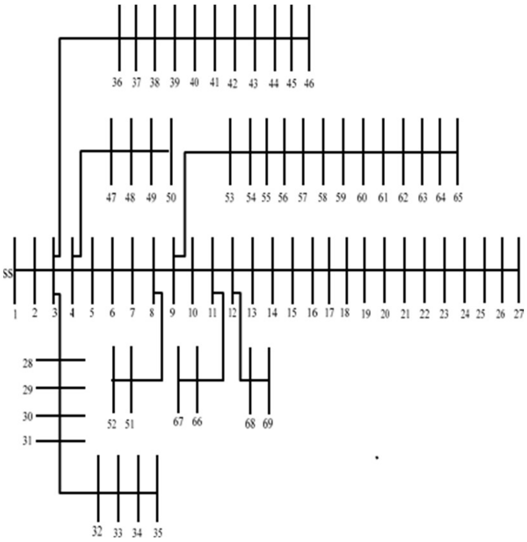

Fig. 8 Sample line diagram of standard 69-bus test system

The IEEE 69-bus test system, depicted in Fig. 8, serves as the foundation for the upcoming case study. With a radial system and a substation voltage of one, the system consists of 69 buses and 68 branches. The purpose of this large-scale system is to verify whether the suggested technique is feasible. The results were compared with those obtained while considering alternative techniques in to consideration to verify the efficiency of the suggested strategy for determining the best location for DSTSTCOM.

Results for a 69-bus system under various load scenarios are displayed in the table below.

Table: 3 Results for 69-bus system

Loading Condition	Losses without device (kW)	Location of device	PSO	
			Size of device (kVAr)	Losses with device in (kW)
Normal	225.0044	61	1330	152.04
125%	369.0664	61	1675.1	246.04
150%	560.5439	61	2026.7	367.79
175%	809.4927	59	2517.8	555.70

The table 3 demonstrates that the overall losses of the 69-bus system in the absence of a device, under normal loading conditions, are 225.0044 kW. The losses are decreased to 152.0446 kW once the device is positioned at the 61st bus, and a device with 1330 kVAr is required to accomplish this reduction in losses. When the device is installed at the 61st bus, the overall losses at the 69-bus system without a device, under 125% loading circumstances, are reduced to 246.0443 kW. This decrease in losses requires a device size of 1675.1 kVAr.

The total losses for the 69-bus system without device at 150% loading circumstances is 560.5439 kW. Once the device is positioned at the 61st bus, the losses are decreased to 367.7904 kW, and this reduction in losses requires a device size of 2026.7 kVAr. Under 175% loading conditions, the overall losses of the 69-bus system in the absence of a device are 809.4927 kW. After the device is installed at the 59th bus, the losses are decreased to 488.6277 kW, and this reduction in losses requires a device size of 2517.8 kVAr.

A graphical illustration of the 69-bus system under various load scenarios is shown in Fig. 7.

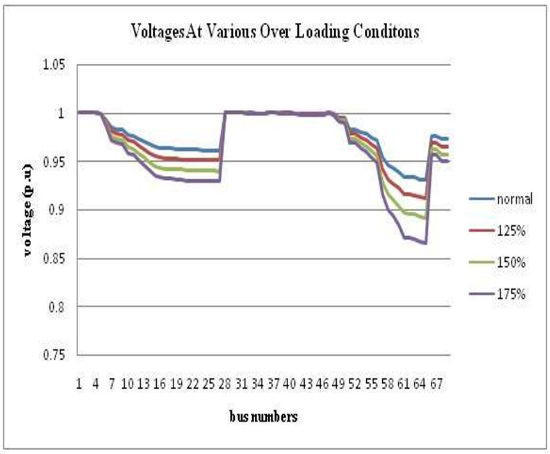

Fig: 9 A graphical representation of the 69-bus system under different load scenarios

The obtained results are compared with the Immune Algorithm for the IEEE 33-bus system to demonstrate the effectiveness of the current technique.

Table 4: Results for IEEE 33 bus system

Comparison	**Immune Algorithm**	**PSO**
Losses before placement in kW	245.68	202.7661
Location of the device	30	30
Size of the device in KVAr	1339.67	1253.2

Loss after placement of the device in kW	169.78	143.6445

The obtained results are compared with the Immune Algorithm for the IEEE 69-bus system to demonstrate the effectiveness of the current technique.

Table 5: Results for 69 bus system

Comparison	Immune Algorithm	PSO
Losses before placement in kW	276.45	225.0044
Location of the device	61	61
Size of the device in KVAr	1456.54	1330
Loss after placement of the device in kW	169.89	152.0446

7 Conclusions

This study explored the complex field of reducing power losses and improving voltage profiles by carefully placing Distribution Static Compensators (DSTAT COM) to provide a more effective, dependable, and adaptive power system operation. The PSO (Particle Swarm Optimization) algorithm in conjunction with Fuzzy Logic proved to be a reliable method for handling the intricacies present in power distribution networks.

There are several important stages to the project's methodical investigation. The first emphasis was on comprehending the basic elements of the power system and realizing how crucial it was to reduce power losses and maintain a steady voltage profile. It became clear that the key to accomplishing these goals is the adoption of cutting-edge technology like DSTATCOM. The ouput results are validated in MATLAB Simulink Platform.

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