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Congestion Management of Power Systems by Optimal Allocation of FACTS devices using Hybrid Techniques

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ABSTRACT- For system operators, Congestion management is a difficult task as the market's security and reliability are protected by this methodology. As the magnitude of an electric transmission system is extremely dynamic, limits must be estimated much beforehand, in order to manage the congestion issues at the right time. Flexible AC transmission systems (FACTS) are used to control voltage fluctuation by adjusting the system's real and reactive power. A combination of Improved Remora Optimization (IRO) and Improved Radial Basis Function (IRBF) is used to allocate positions and sizes of the FACTS devices. In this study, Static Synchronous Compensator (STATCOM), Interlink Power Flow Controllers (IPFC) and Unified Power Flow Controllers (UPFC) are among the FACTS devices used. In the proposed hybrid IRO-IRBF technique, following are the functional aims calculated: build-on-expenditure, Line Loading (LL), Total Voltage Deviation (TVD) and real power loss. Additionally, the hybrid IRO-IRBF technique is used to confirm the proper location using the IEEE 30 bus structure. TVD, power loss, installation costs, and line loading are the measurements used to assess the implementation performance of the hybrid IRO-IRBF approach. From the result analysis, the hybrid IRO-IRBF achieved a real power loss of 0.1591 p.u., and TVD of 0.02 p.u., which is lesser than the existing Whale Optimization Algorithm and Mayfly Optimization Algorithm.

General Terms- Congestion management, FACTS, Optimization Algorithm, Power System, Transmission Control.

Keywords- Flexible ac transmission systems, improved radial basis function, improved remora optimization, interlink power flow controller, static synchronous compensator, unified power flow controller.

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1. INTRODUCTION

At present, power electronics is highly more efficient than the conventional techniques [1], which are reliable on electrical technology, lag behind in speed and cost-wise are expensive [2]. However, it is possible to use FACTS devices powered by semiconductors for a much more optimized utilization of the current electric systems [3]. The concept of FACTS devices are applied to harmonic compensation, load control, voltage stabilization, power quality assessment, and reactive power compensation [4]. Power loss minimization, voltage stabilization, reactive power management, and congestion control are examples of further uses [5]. A sizable data collection is always necessary to determine the best positions and settings for FACTS-based electrical networks [6]. Even a successfully implemented algorithm that offers a precise optimal solution to the issue may fail in a simulation situation due to its resolution time or space complexity [7]. Various methods and procedures were utilized in the earlier researches to choose the best positions and configurations for FACTS devices. But the capacity of FACTS controllers to accept control algorithms designed to accomplish numerous objectives distinguishes them from other controller types. The most popular and effective methods are believed to be those that involve metaheuristics [8], [9].

Optimum usage of the electrical network becomes a crucial factor for the modern-era power grids to facilitate execution of functions such as, keeping the voltage stability at every bus within a normal range, improving the voltage integrity of the system, reducing power losses in lines, increasing system authenticity as well as integrity, etc., [10]. Reactive power compensation devices, like the FACTS, are used to achieve these in transmission systems [11]. To ensure adequate expenditure on this equipment, the best position and size of the reactive power compensation mechanisms are vital [12]. Most recent studies have concentrated on methods for locating and sizing different reactive power compensation equipment in the electricity system by utilizing various indices to obtain power loss, voltage stability, voltage level, and line loadability [13].

The current indices used in the methodologies for resolving the issues of optimal size and location for all varieties of reactive compensation equipment, had not been covered in any review papers [14]. The best position and size for FACTS are being studied in the present literature, which comprises quantitative, traditional, and hybrid approaches techniques [15].

The major contribution of this research is specified below:

- Three varieties of FACTS are used to improve voltage saturation in the supply line system by controlling real and reactive power.
- The FACTS devices are set up and sized correctly utilizing the combination of IRO and IRBF. For FACTS device placement, IRO incurs reduced computational complexity.
- Moreover, the IRBF has an increased possibility of exploration and misuse. The FACTS devices are placed optimally to attain reactive power compensation and execution of increased power transfer.

The following is the formation of this study paper: The literature review of contemporary ideas for efficient placement of FACTS devices is discussed in *section 2*. *Sections 3* and *4* discuss the formulation of issues and designing of the FACTS devices, respectively. In *section 5*, the working of the hybrid IRO-IRBF model, using IRO and IRBF, is detailed. In *section 6*, the hybrid IRO-IRBF technique's experimental output and comparative studies are shown. Finally, *section 7* comprises the conclusion.

2. LITERATURE REVIEW

The challenge of maintaining an efficient load flow in a power system was successfully solved by Singh et al. [16]. The Hybrid Sine-Cosine Algorithm (HSCA), which is a novel hybridization of the population-based Sine-Cosine Algorithm (SCA) and the arithmetic crossover function, resulted in speedy calculation and improved the individual's ability to find a global solution while avoiding local optima. Moreover, IPFC was properly positioned in the power system to regulate and enhance the parameters. Utilizing current injection modelling, it was mathematically structured to incorporate IPFC in Newton-Raphson load flow. Sine-cosine function was used to manage the exploitation and exploration, but it took a considerable amount of time to get the optimal outcome.

Using the Whale Optimization Algorithm (WOA), Nadeem et al. [17] established the best placement, sizing, and synchronization of FACTS devices in transmission networks. By building PV curves for load buses and using the line stability index, unstable buses and lines were identified in order to establish the most suitable places for these devices to be connected. The WOA was then used to determine the best rating for these components as well as to identify the working methodology of SVC, TCSC, and UPFC in conjunction with the network's existing reactive power sources. The reduction in active power losses and the costs of FACTS device, which make up the system's operational costs, was the aim here. Although cost restraints restrict their applicability, UPFC controls all of the variables.

Using FACTS devices based on the Mayfly Optimization Algorithm (MOA), Amarendra et al. [18] showed how to improve stability. Reduced losses and increased system stability were the key goals of the suggested methodology. The losses were greatly reduced by the use of FACTS controllers like STATCOM, TCSC, IPFC, and UPFC. These Power electronics had a very effective mayfly optimization algorithm to reduce losses. Reduction in fuel costs and losses, as well as increased operating flexibility in dangerous situations, are all advantages of utilizing Facts devices. However, system security restrictions were not imposed by these techniques.

Siddiqui [19] presented the line flow sensitivity factor (LSF) which was a novel sensitivity index used to discover the ideal position of IPFC while its control parameter setting was optimally attained using the particle swarm optimization algorithm. As a result, LSF was offered as a method for properly positioning IPFC in the transmission network. LSF was calculated using the change in power flow across the lines as a function of IPFC control parameters. PSO was used to find the best IPFC reactance setting. However, the stated results demonstrate that placing an IPFC in the particularly identified position does not relieve system congestion.

Optimization of voltage security was demonstrated by Okampo et al. [20] by positioning of FACTS devices using modified Newton-Raphson method. This research focused on examining the effectiveness of IPFCs for controlling fluctuation while enhancing voltage. To increase voltage stability and sustain active power flow, the presented Newton-Raphson was further modified with an IPFC variable to solve the issue of load flow problem. The updated approach was successful because the IPFC in a power distribution system produces a stable voltage profile and enhances active power flow. Also, this strategy yielded a solid, accurate result, much like all other quantitative optimization methods, although it consumed a longer computation time than the metaheuristic methods, which have been favoured for bigger network systems.

Sivakumar et al. [21] suggested a Water Wave Optimization (WWO) Algorithm for optimal FACTS placement in deregulated power systems for congestion management, in which the WWOA's concurrency behavior and computation ability were demonstrated. The ability of the Water Wave Optimization Algorithm to optimize the power system parameters was outstanding, and it was capable of convergence with a higher quality outcome, according to the results' evaluation. It also required fewer rounds and lower computational time. Therefore, WWOA was concluded as a reliable and capable method for solving multi-objective optimization problems. However, this strategy did not account for the examination of the power system's reactive power transfer.

3. PROBLEM FORMULATION

IRBF is exploited to find idealistic positions for 3 FACTS: UPFC, STATCOM and IPFC. Total voltage variance, LL, and real Ploss are all adjoined in the multipurpose function. The following is a description of the various objective functions:

3.1 Generation Cost

The production cost is initially estimated by the system's active and reactive power production costs.

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3.2 Total Voltage Deviation
A smaller voltage gap in the system lowers the voltage deviation. TVD is the voltage difference between the reference and bus voltages.

3.3 Line Loading
In transmission systems, line overload is reduced to keep the power flow within a defined range. The limit value N is narrowed by LL in the power flow gap.

3.4 Real Power Loss
The transmission line produces both reactive and actual power as a result of the exchange between creator and demand nodes. The equation illustrates the goal of reducing real power loss in transmission lines.

4. MODELLING OF FACTS DEVICES
FACTS are exploited by the network to produce a dependable, secure, and stable system. Therefore, choosing the appropriate distribution from FACTS is essential for the allocation [22].

4.1 Static Synchronous Compensator (STATCOM)
The STATCOM is a FACTS component that is shunt linked. It comprises of a coupling transformer that connects a voltage source converter to the bus. According to Figure 1, it is represented as a voltage source connected in series with a coupling transformer resistance. The STATCOM can concurrently supply inductive and capacitive reactive power to the transmission network, but it cannot generate or consume active power. While it is helpful in regulation of voltage, STATCOM also improves control performance for transient conditions, dampens system oscillation, applies harmonic filters, and offers quick reactions when the loads reactive power changes rapidly. Moreover, the STATCOM represents the only FACTS component that is able to deliver unity power factor to account for minute voltage changes.

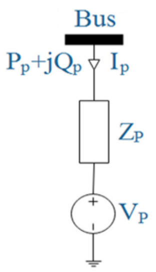

Figure 1: Equivalent Circuit of STATCOM

4.2 Interlink power flow controller (IPFC)
IPFC is a class of equipment that is frequently employed for concurrent or user-defined transmission lines. Within an identical power transmission sector, the IPFC regulates the power flow in transmission lines. The IPFC measures real power flow, as well as active and reactive flow since it includes both series and shunt converters. By adjusting the voltage level, line reactance, and phase angle, the IPFC checks the efficiency of power lines. By introducing the voltage in a series with a transmission line, the SSSC in the IPFC offers series compensation. By introducing parallel current to transmission lines, it supplies the shunt correction for the STATCOM in the IPFC. *Figure 2* shows the IPFC's equivalent circuit.

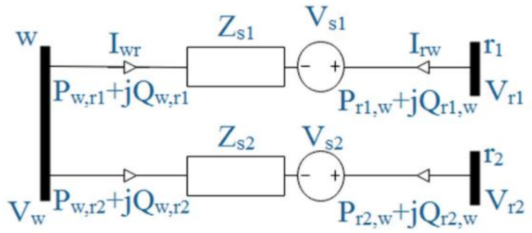

Figure 2: Equivalent Circuit of STATCOM

4.3 UPFC modelling
The UPFC device being an adaptable FACTS controller, swiftly modifies the actual and reactive power flow across the power system network by adjusting impedance, phase angle, voltage, and other parameters. IPFC and STATCOM are linked in a line or bus to simulate the UPFC. *Figure 3* shows the equivalent circuit. Additionally, the change in the Jacobian matrix caused by proper power supply, results in equal reactance between the two nodes.

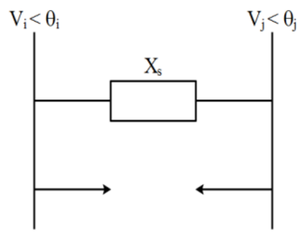

Figure 3: Equivalent Circuit of UPFC

5. HYBRID IRO-IRBF METHOD
This hybrid IRO-IRBF approach uses a mix of IRO and IRBF algorithms for most suitable allocations of the FACTS gadgets. The five main steps in the hybrid IRO-IRBF-based allocation include reading system data, configuration settings, set-up of FACTS devices, deriving an optimal allocation from the hybrid IRO-IRBF algorithm, and validating the final position with the base case value. Three distinct FACTS gadgets are employed in this hybrid IRO-IRBF: STATCOM, IPFC, and UPFC. *Figure 4* depicts the block diagram of hybrid IRO-IRBF.

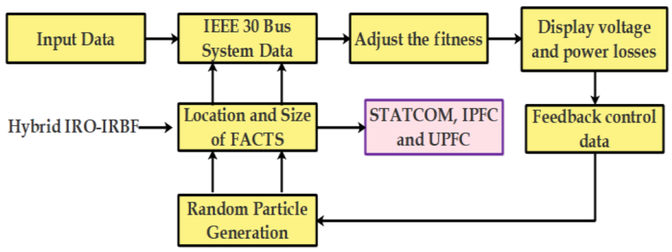

Figure 4: Block diagram of hybrid IRO-IRBF

The general allocation procedure for FACTS devices involving utilization of IRO-IRBF for congestion management, is as follows:

Step 1: Initialize the procedure using standard control parameters found in the algorithm.
Step 2: For the IEEE-30 bus system, read the line data and bus data.
Step 3: The initial random particle creation procedure will take place in the data stated above. A load flow analysis check will also be made.
Step 4: For each bus in the system, calculate the power flow analysis and Line Utilization Factor (LUF). After that, execute the research algorithm's fitness function.
Step 5: Find the best fitness values from the data to provide to the system, which will then process the data once again in step 6.
Step 6: In order to determine the ideal fitness values while taking the IRO-IRBF into account, test the load flow analysis using the proposed technique.
Step 7: Compare the congestion values acquired before and after the FACTS installation after completing the LUF.
Step 8: Proceed until the congestion values after the FACTS placement are within the set limit. Otherwise, initiate *Step 2*.

5.1 Improved Remora Optimization Algorithm

A metaheuristic optimization technique called the ROA [23] imitates the behavior of remora fish. Remoras team together with sailfish, whales, or other species to search for food to avoid hostile invasion and conserve energy. As a result, when updating locations, ROA uses several Sailed Fish Optimizer (SFO) & Whale Optimization Algorithm (WOA) algorithms. They will execute host feeding if changing the host is not necessary.

5.1.1 Iterative process

5.1.1.1 SFO Process

When the remora is attached to the sailfish, it appears as though the remora is moving with the sailfish. According to this significant approach, the SFO technique formulae are improved, and the following *equation (1)* is represented as follows:

$$Z_i^{ct+1} = Z_{Best}{}^{ct} - \left(rand \times \left(\frac{Z_{Best}{}^{ct} + Z_{rand}{}^{ct}}{2}\right) - Z_{rand}{}^{ct}\right) \quad (1)$$

Where ct is the current iteration number, $Z_{Best}{}^{ct}$ is the current best position, Z_{rand}^{ct} is the remora's current random position [21].

5.1.1.2 Experience Attack

When remora is bound to the hosts, they move in a restricted area around the hosts to ascertain whether they desire to be replaced. This process is much like trying to grasp a new concept. The formula for statistical computation is displayed in *equation (2):*

$$Z_{tm} = Z_i^{ct} + (Z_i^{ct} + Z_{ppg}) \times randn \quad (2)$$

Where Z_{tm} is the remora's tentative movement, Z_{ppg} is the position of remora's prior generation, $randn$ is the random number with normal distribution among 0 & 1.

Equation (3) states that the remora assess whether to switch hosts after such a little movement range, and *equation (4)* is formulated for switching hosts:

$$f(Z_i^{ct}) < f(Z_{ppg}) \quad (3)$$

$$H(i) = round(rand) \quad (4)$$

Where $H(i)$ the hosts specifies consumed by remora and has a starting value of 0 or 1. When $H(i)$ equals 0, the sailfish is consumed; when $H(i)$ equals 1, the whale is consumed. Furthermore, $round$ is a rounded function, and the fitness values of Z_i^{ct} and Z_{ppg} are $f(Z_i^{ct})$ and $f(Z_{ppg})$ respectively [21].

5.1.1.3 WOA Process

The remora moves on time with the designated host whenever a whale is taken into account as the host. The calculation formulae for WOA are mentioned as *equations (5), (6), (7) & (8)*:

$$Z_i^{ct+1} = DT \times ec^r \times cos(2\pi a) + Z_i^{ct} \quad (5)$$

$$DT = |Z_{Best}{}^{ct} - Z_i^{ct}| \quad (6)$$

$$r = rand \times (a - 1) + 1 \quad (7)$$

$$la = -\left(1 + \frac{ct}{MT}\right) \quad (8)$$

Where DT is the distance among the optimal & current locations before the updation, ec is a constant with a value of approximately 2.7182, & r is a random number among -1 & 1. MT is the maximum number of iterations, whereas la is the linear drop among [-2, 1] at the time of iteration.

5.1.1.4 Process of Host Feeding

The variation of the search process is constrained, and the host's feeding phase is a portion of the exploitation phase. Around the hosts, the remora look for food. The statistical calculations are mentioned as equations (9), (10), (11) and (12):

$$Z_i^{ct+1} = Z_i^{ct} + RA \quad (9)$$

$$RA = RB \times (Z_i^{ct} - C \times Z_{Best}) \quad (10)$$

$$RB = 2 \times RV \times rand - RV \quad (11)$$

$$RV = 2 \times \left(1 - \frac{ct}{MT}\right) \quad (12)$$

Where RA is the remora's moving distance, which is proportional to the remora's as well as the host's volume. The remora factor C is utilized to determine the remora's location and is defined as 0.1 in ROA. RV is utilized to mimic the remora's volume, whereas, the RB is utilized to imitate the volume of the host.

5.1.1.5 Process of Host Feeding

After an experience attack, ROA evaluates whether the host wishes to be modified. The status of the remora and the current hosts are related to the experience attack. Remora mainly rely on their hosts for nourishment and have a limited ability to find food on their own. They risk starvation if they stay in one host for too long. This study provides a novel host-switching technique that reconsiders the host's environment before deciding whether to move the hosts or not. The aforementioned technique lessens the impact of remora's ability to feed on itself. Based on the foraging behavior of the remora discussed before,

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the following optimization ideas are improved by using the *equations (13), (14), (15), (16) and (17)*:

$$Z_{new} = Z_i^{ct} + k \times step \text{ if } rand < LP \tag{13}$$

$$k = \beta \times (1 - rand) + rand \tag{14}$$

$$step = Z_{r1}{}^{ct} - Z_{r2}{}^{ct} \tag{15}$$

$$LP = 0.5\left(2 - \frac{ct}{MT}\right) \tag{16}$$

$$f(Z_i^{ct}) < f(Z_{new}) \tag{17}$$

Where Z_{new} is a new solution, k is a random factor, and β is a constant with a value of 0.2. The distance among two random solutions is represented by $step$. The two randomly generated solutions are denoted by Z_{r1}^{ct} and Z_{r2}^{ct}. The fitness value of Z_{new} is given by $f(Z_{new})$. LP is a decreasing factor that ranges from 1 to 0.5. It is used to control how frequently new solutions are developed. From the aforementioned approach, *equation (13)*, generates a new solution based on the existing one and examines the fitness value of both the new and existing solutions. The update process of the solution is changed if the new solution has a higher fitness value [24].

5.5.1 *Radial Basis Functional Network*

The variation of the radial function which creates a radial network for simplicity in the process, is the feedforward neural network [25]. This strategy functions similarly to the backpropagation method, which is covered in depth. In this instance, the voltage/current for the output is passed into RBFN, which determines the duty cycle value. The converter's duty cycle is produced using RBFN, and the process of RBFN is shown by *figure 5*.

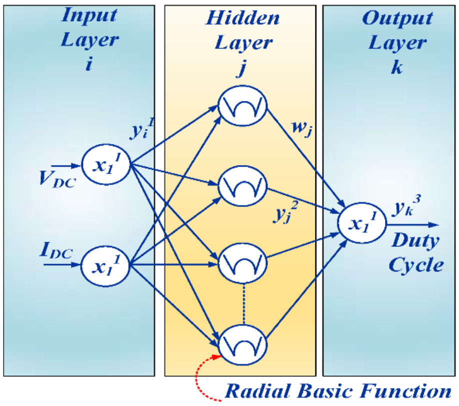

Figure 5: Process of RBFN

5.2 Improved Remora Optimization Algorithm

RBF designs are represented differently depending on number of nodes present in the hidden layer. RBF creation is usually viewed as a development issue that is altered by weight. The nodes in the hidden layer are labelled using enhanced RBF-FRA, which has a cumulative effect on the node in the output hidden layer. Consequently, the overall impact is changed to the *equation (18)*.

$$J_k = \frac{1}{N}\sum_{t=1}^{N}\frac{e_k^2(t)}{R_k^2(t,t)}, \quad k = 1,2 \ldots n. \tag{18}$$

Samples are characterized as N, hidden layer nodes are chosen as n, and errors are specified as $e_k(t)$ and $R_k(t,t)$.

5.2.1. *Fitness Function (FF) derivation*

This section derives the fitness function (FF) for the hybrid IRO-IRBF technique. The FF's expression is given in the following *equation (19)*.

$$f = \begin{cases} \max (V) \\ \min (Q_{load}, P_{load}, P_{loss}) \end{cases} \tag{19}$$

Q_{load} and P_{load} correspondingly are the reactive and real powers. *Equation (19)* is used to attach FACTS devices appropriately. To cut power loss and enhance voltage profile, FACTS devices are put in carefully chosen locations. The IRO has a reduced computing complexity in big systems. This hybrid IRO-IRBF produces the ideal placement and size for FACTS in IEEE 30 bus.

6. RESULT AND DISCUSSION

In this part, the simulation findings and analysis of the hybrid IRO-IRBF technique-based optimum FACTS device allocation is explained.

6.1 Normal or Body Text

The performance efficacy of the hybrid IRO-IRBF method is evaluated in terms of TVD, power loss, line loading, and device cost. To address the multi-objective problem, FACTS devices are arranged on IEEE 30 bus system as seen in *table 1*. The following are the results of the performance analysis for five different scenarios:

Table 1. Scenarios of IEEE 30 bus system

Scenarios	FACTS
1	No Devices
2	STATCOM
3	IPFC
4	UPFC
5	Multi-devices (STATCOM, IPFC, UPFC)

Table 2 displays the IEEE 30 bus performance for Scenario 1. In this case, using FACTS devices to address the RPD issue is a must. In a transmission system without FACTS devices, the values for TVD, P loss, and LL are 0.9845 p.u., 7.5847 MW and 7.895 respectively. *Figure 6* shows the fitness function for the 1st scenario.

Table 2. Evaluation study without FACTS

Parameters	Standard	Optimized
V8	1.0100	1.0262
V5	1.0100	1.0099
V2	1.0400	1.0198
V13	1.0500	1.0323
V11	1.0500	1.0296
V1	1.0500	1.0439
T36	1.0680	0.9615
T15	1.0320	0.9943
T12	1.0690	1.0247

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T11	1.0780	0.9541
Qc29	0	1.2411
Qc24	0	3.1675
Qc23	0	3.0416
Qc21	0	2.7782
Qc20	0	2.8385
Qc17	0	2.6702
Qc13	0	2.2694
Qc12	0	2.8731
Qc10	0	3.5583
TVD (p.u)	1.85	0.9845
Ploss (MW)	7.84	7.5847
LL	8.35	7.895

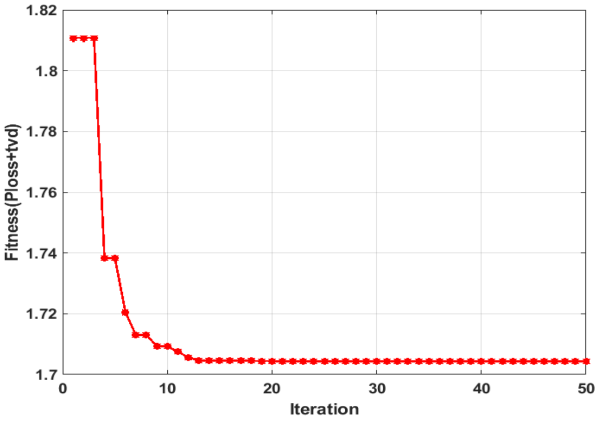

Figure 6: FF for scenario 1

For scenario 2, the values of TVD, Ploss, and LL are 0.02 p.u, 5.3365 MW, and 7.5849, respectively. The STATCOM measures 17 and is positioned at position (0.4586), respectively. The STATCOM employed in this scenario 2 is also expensive, costing 145.258 $/MVAR. Table 3 shows that scenario 2 has a lower TVD, Ploss, and LL over the previous scenario 1. Figure 7 shows the fitness function for the 2nd scenario. Table 4 shows the performance analysis of scenario 3.

Table 3. Evaluation study for STATCOM

Parameters	Standard	Optimized
V8	1.0100	1.0087
V5	1.0100	1.0331
V2	1.0400	1.0390
V13	1.0500	0.9909
V11	1.0500	1.0365
V1	1.0500	1.0299
T36	1.0680	0.9801
T15	1.0320	0.9537
T12	1.0690	0.9928
T11	1.0780	0.9982
Qc29	0	2.4739
Qc24	0	2.6004
Qc23	0	3.1345
Qc21	0	2.4162
Qc20	0	3.2586
Qc17	0	3.5854
Qc13	0	2.2657
Qc12	0	1.5403
Qc10	0	2.1377
LL	8.25	7.5849
Ploss (MW)	5.74	5.3365
cost ($/MVAR)	-	145.258
location	17	17
size	0	0.4586
TVD (p.u)	1.47	0.02

Table 4. Evaluation study for IPFC

Parameters	Standard	Optimized
V8	1.0100	1.0289
V5	1.0100	1.0676
V2	1.0400	1.0644
V13	1.0600	0.9691
V11	1.0600	1.0653
V1	1.0700	0.9862
T36	1.0780	0.9690
T15	1.0420	0.9683
T12	1.0790	0.9000
T11	1.0980	1.0550
Qc29	0	2.4741
Qc24	0	3.2304
Qc23	0	0.0992
Qc21	0	4.4321
Qc20	0	2.4885
Qc17	0	4.0393
Qc13	0	5.0000
Qc12	0	2.3654
Qc10	0	2.9367
LL	7.25	5.0755
Ploss (MW)	6.29	6.817
cost ($/MVAR)	-	168.359
location	16	17
size	0	0.256
(p.u)	2.25	0.0125

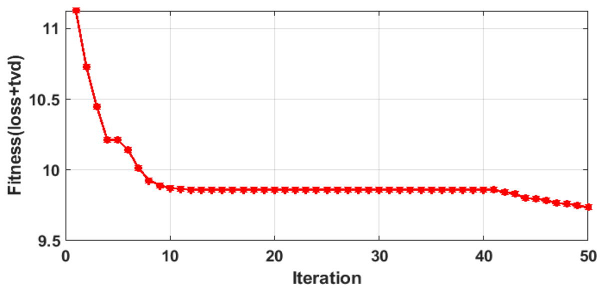

Figure 7: Fitness graph for scenario 2

Among the FACTS devices, IPFC is used to fix the RPD issue. The values for TVD, Ploss, and LL in a transmission using the IPFC are, respectively, 0.2025 p.u, 6.817 MW, and 5.0755. Length and position of the IPFC are 17 and 0.0125, respectively. The IPFC charges per MVAR, for the bus system, is also 168.359 dollars. In Figure 8, the FF graph of scenario 3 is depicted.

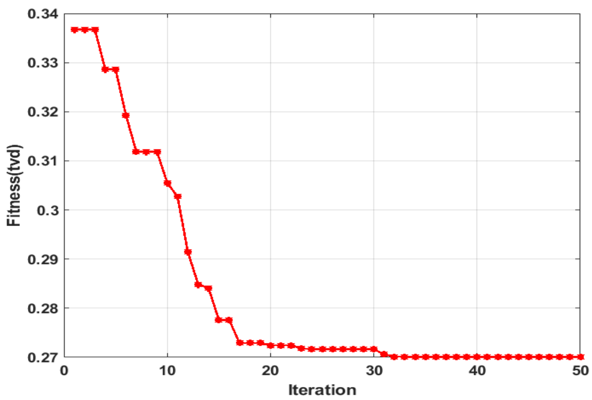

Figure 8: FF for scenario 3

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For scenario 4, TVD, Ploss, and LL are measured at 0.1258 p.u., 4.690 MW, and 4.6859, respectively. The UPFC is sized at about 0.9975 and is found at position 28. The UPFC employed in scenario 2 also costs 198.2545 $/MVAR. Table 5 shows the performance analysis of scenario 4 in which the values of TVD and Ploss, are 0.2556 and 0.1591 p.u respectively. Figure 9 displays the fitness graph for UPFC.

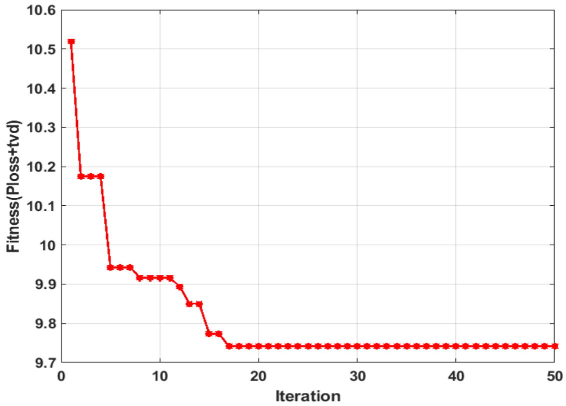

Figure 9: FF for scenario 4

Table 5. Evaluation study for UPFC

Parameters	Standard	Optimized
V8	1.0100	1.0479
V5	1.0100	1.0196
V2	1.0400	1.0650
V13	1.0500	0.9788
V11	1.0500	1.0503
V1	1.0500	1.0534
T36	1.0680	0.9970
T15	1.0320	0.9861
T12	1.0690	1.0540
T11	1.0780	0.9567
Qc29	0	3.0487
Qc24	0	1.6346
Qc23	0	2.3348
Qc21	0	2.7643
Qc20	0.	3.2344
Qc17	0	0.7656
Qc13	0	0.2863
Qc12	0	0.7125
Qc10	0	1.9261
LL	7.58	4.6859
loss (p.u)	-	0.1591
TVD (p.u)	2.05	0.2556
cost ($/MVAR)	-	198.2545
degree	0.	0.659
impedance	0	0.4561
location	0	28.0000
size	0	0.9975

Similarly in scenario 6, 0.9985 p.u., 4.685 MW, and 5.2659 are situated at positions 16, 25, and 6. Utilizing the hybrid IRO-IRBF, the UPFC, STATCOM and IPFC sizes were cost-wise optimized to be 51.2602 $/MVAR, 0.9985 $/MVAR, and 0.9943 $/MVAR, respectively. The UPFC, STATCOM and IPFC expenses in scenario 5 are 139.2545, 172.9854, and 190.9845 $/MVAR, correspondingly. Table 6 demonstrates that the TVD and P loss determined in scenario 5 are smaller than those determined in scenarios 1, 2, and 3. Figure 10 displays the FF graph for Scenario 5.

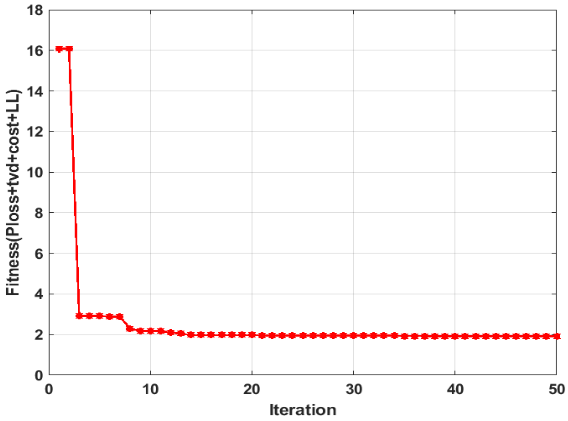

Figure 10: FF for scenario 5

Table 6. Evaluation study with multiple FACTS

Parameters	Standard	Optimized
V8	1.0100	1.0251
V5	1.0100	1.0706
V2	1.0400	0.9770
V13	1.0500	0.9951
V11	1.0500	0.9574
V1	1.0500	0.9564
T36	1.0680	1.0236
T15	1.0320	1.0076
T12	1.0690	0.9684
T11	1.0780	0.9515
Qc29	0	1.9355
Qc24	0	2.9427
Qc23	0	2.1248
Qc21	0	3.6634
Qc20	0	1.4142
Qc17	0	3.1690
Qc13	0	2.6516
Qc12	0	4.0131
Qc10	0	0.6943
LL	7.58	5.2659
Ploss (MW)	6.25	4.8442
cost ($/MVAR)	-	139.2545
location	0	17.0000
size	0	51.2602
cost ($/MVAR)	-	172.9854
location	0	45.0000
size	0	1.0140
TVD (p.u)	2.05	0.9985
cost ($/MVAR)	-	190.9845
degree	0	0.4585
impedance	0	1.95
location	0	9.5484
size	0	1.5845

6.2 Comparative Analysis

To determine the usefulness of the hybrid IRO-IRBF method, its performance is compared to that of existing techniques. The hybrid IRO-IRBF technique is validated in terms of various performance metrics. Mayfly Optimization Algorithm (MOA) [18] is among the existing methodologies taken for comparison. And additionally, for further comparative analysis, the hybrid IRO-IRBF approach is also validated in the 30 bus system. The MOA method is developed for devising the optimal STATCOM locations [18].

Table 7. Comparative analysis of Voltage Deviation with STATCOM

Constraints	Existing MOA [18]	Hybrid IRO-IRBF
TVD (p.u)	0.06	0.02

Table 7 displays the contrasting results derived between the MOA [18] method and the hybrid IRO-IRBF methodology. The hybrid IRO-IRBF technique, as shown in the table, achieves a TVD of 0.02 pu, which is lesser than the MOA [18]. The generation cost and line loading are not taken into account by the MOA [18] while determining the best location for FACTS devices. On the contrary, the hybrid IRO-IRBF method considers four independent objective functions: the cost of the generating system, overall voltage variance, load on the lines, and the real power loss.

Table 8. Comparative analysis of Real Power Loss with UPFC

Constraints	Without FACTS	With UPFC			
		PSO	GA	WOA [17]	Hybrid IRO-IRBF
Real Power Loss (pu)	0.1849	0.1719	0.1636	0.1627	0.1591

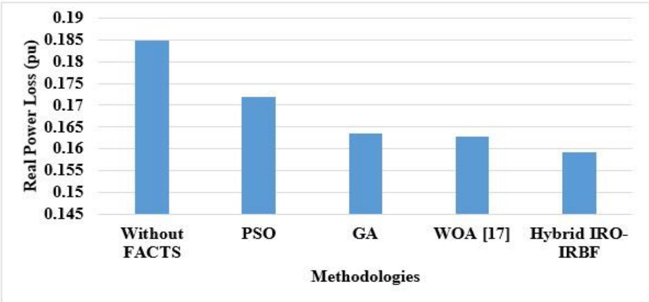

Figure 11: Comparative analysis of real power loss

The comparative examination of real power loss is shown in Figure 11. The comparison of available approaches is shown in Table 8. When compared to existing Particle Swarm Optimization (PSO), Genetic Algorithm (GA) and WOA [17], hybrid IRO-IRBF provides better results in real power loss. For all FACTS devices, the proposed IRO-IRBF provides superior results in all circumstances.

6. CONCLUSION

In this paper, hybridization of IRO-IRBF to facilitate ideal positioning as well as sizing of FACTS has been successfully executed. The IRO and IRBF are used for optimal placement because of their less troublesome computational demands. FACTS such as IPFC, UPFC and STATCOM, are utilized to manage the actual and reactive power to increase the voltage stability of the transmission line system. Reactive power compensation, security, augmentation of the power transfer capabilities, and reliability are all achieved in the transmission line systems through the usage of FACTS devices. The hybrid IRO-IRBF technique provides a lower TVD and loss than the existing Mayfly Optimization Algorithm. The hybrid IRO-IRBF achieved a real power loss of 0.1591 p.u., and TVD of 0.02 p.u., which is lesser than the existing Whale Optimization Algorithm. In future, this research will be further extended by using various FACTS devices with novel hybrid algorithms under large bus systems.

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