Optimal setting of interline power flow controller in deregulated power systems congestion management by using artificial intelligent controllers

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Abstract: In electricity market with a deregulation with many times will become difficult for dispatching power, whish is obtained with the power congestion in transmission lines due to flow of power in buses. To reduce the flow of power in buses and system loss in lines which are heavily loaded, to improve loadability and system stability for which an Interline Power Flow Controller used. In this article, Disparity Utilization Factor for Line is utilized with the optimal tuning and placement with Gravitational Search Algorithm IPFC hinged transmission lines for power congestion. The ranking of transmission lines by line congestion in terms of relative DLUF. According to the IPFC placement with the essential minimum congested, weak line connected to the same bus in the congested distribution network. IPFC optimal Sizing is carried with Gravitational Search Algorithm. The multiobjective function is chosen for parameters tuning of IPFC. A suggested IEEE-30 bus test network is implemented by a graphical representation which is considered in this study to reduce LUF in transmission lines with IPFC optimal placement. Both active power losses and reactive power losses in power system are necessary to be minimized after every iteration of IPFC optimal tuning. The proposed tuning in this article gives effectiveness with the reduction in the values of power system with the objective functions.

Keywords: Line congestion, power loss, adaptive moth swarm optimization, Thyristor-controlled series capacitor, FACTS.

1. Introduction
Nowadays the electricity demand goes on increasing that made the congestion management a troublesome errand. If the system functions beyond the limits of power transfer with the transmission system which is considered to be congested [1]. Most common factors for congestion are old transmission networks, installation of renewable energy resources thus enhancing the penetration as well as increasing electricity demand. In addition to this, the congestion happens while the transmission line fails to transmit the power based on the market necessity. Congestion management is therefore a necessary library for considering the power necessary for system hindrances breaking or limitations [2]. The term congestion management is capable of mitigating and avoiding congestion. Congestion management is broadly classified into non-price-free techniques and price-free techniques.
The price-free technique comprises topology network modification, transformer tap installation as well as the functioning of various compensating devices namely flexible AC transmission system (FACTS), phase shifters, etc. The non-cost-free technique is accomplished by the use of curtailment of load transactions, load curtailment as well as generator rescheduling [3]. The consequences based on different algorithms for congestion management, which are observed huge no. of measurements in electrical market reconstruction; since the consumption of consumers with a large amount of electrical energy. The congestion can be mitigated by managing and controlling the flow of real power in the transmission system [4].

Meanwhile, there occurs redistribution of power if the transmission lines are interconnected with other transmission lines. On the contrary, there are few transmission lines located apart that do not transmit additional power and functions under the rated value [5]. If this operation prolongs for a long period, because of uncontrolled loop flows the system becomes overloaded. For this reason, the congestion management must be carried out over a small-time duration thereby ensuring the security of the system. In the beginning, very big business organizations relished monopolization and they took responsibility regarding complete power generation [6].

In general, transmission and distribution are in terms referred to as vertical integration utilities. However, with the available capacitive power plants and renewable resources, an ordinary human being can generate electric power and can transfer the electric power to the grid that made the reconstruction process more significant [7]. In addition to this, there are several ways to minimize congestion. Utilizing FACT device is considered as one of the most significant ways to minimize congestion since the optimal power flow limitations are mitigated by the power flow control [8]. One of the power electronic devices like Thyristor controlled series capacitor among FACT devices that is capable of reactive power generation. The TCSC is employed in such a way that the construction and installation are quite easier and assists in mitigating the congestion at a short duration of time [9]. From the past few years, the optimal location is determined with its size of the devices have considered in terms of optimization issues. Therefore, several techniques have been established to estimate the size and optimal location in accordance with generation loss, cost as well as generation capacity [10].

The significant objective of this approach involved in determining optimal location by setting the proper location of fact devices. The integration of wind farm with profit maximization in deregulated power market contingency constraints by using moth flame optimization algorithm was established by Gope et al. [18]. The significant objective was to reduce system loss and fuel cost. By utilizing this approach, the profit was high with low power quality. Nadeem et al. [19] proposed a sizing, optimal placement and FACTS devices coordination in transmission networks hinged whale algorithm. The main intention of this approach was to minimize operating cost and power loss. Total cost, operating cost, reactive loading, net saving, bus voltage were the measures employed for simulation.

But poor coordination of FACTS was regarded as the major issue. The FACTS devices power management in transmission lines and congestion by using Krill herd technique was demonstrated by Kaur et al. [20]. The major significance of this approach was to determine the congested line with minimum loss, congestion and minimum cost. Poor power quality was the major drawback of this approach. The summary of existing literature survey is described in Table 1.

2. IPFC Mathematical Modelling

Two back-to-back DC-AC converters consisting of an IPFC device controller linked to a shared DC connection. Two converters are considered and are included in the equivalent circuit of the IPFC. Including the addition of watt and wattles power flows exiting bus I were provided Pi and, Qin
equations (1) and (2). IPFC device expressions, with watt and wattles power flows, transfer the power in the bus n.

\[ P_i = V_i^2 g_{in} - \sum_n V_i V_n [g_{in} \cos(\theta_i - \theta_n) + b_{in} \sin(\theta_i - \theta_n)] - \sum_n V_i V_{se}n [g_{in} \cos(\theta_i - \theta_{se}) + b_{in} \sin(\theta_i - \theta_{se})] \]

(1)

\[ Q_i = -V_i^2 b_{ii} - \sum_{n=j,k} V_i V_n [g_{in} \sin(\theta_i - \theta_n) - b_{in} \cos(\theta_i - \theta_n)] - \sum_{n=j,k} V_i V_{se}n [g_{in} \sin(\theta_i - \theta_{se}) - b_{in} \cos(\theta_i - \theta_{se})] \]

(2)

Where, \( g_{in} + jb_{in} = \frac{1}{Z_{se}n} \), \( g_{nn} + jb_{nn} = \frac{1}{Z_{se}nn} \), \( g_{ii} = \sum_{n=j,k} g_{in} \), \( b_{ii} = \sum_{n=j,k} b_{in} \)  

3. Factor of Line Utilization

An index with LUF measurement which includes the degree of a transmission line with loading is utilized with ratings of MVA. The connection between the lines for LUF equation between buses i and j are indicated in equ4.

\[ LUF_{ij} = \frac{\text{MVA power flow in line } ij}{\text{Max MVA power flow in line } ij} \]

(4)

LUF is estimated in terms of percentage of transmission line to be utilized to calculate the line congestion with different efficient techniques. The IPFC have two converters roughly connected within transmission lines among common bus. Direct transfer of IPFC real power including common DC link is possible, which is capable to transfer power within load constraints (overloading, underloading). A novel Line Disparity index with Utilization Factor hereby estimated for IPFC optimal placement. The lines utilization between the buses are indicated with DLUF. The difference is an estimation of percentage of line hinged for flow of the power, Lines with similar rating are assumed.

\[ DLUF_{(ij) - (ik)} = \left| LUF_{ij} - LUF_{ik} \right| \]

(5)

Where, \( DLUF_{(ij) - (ik)} \) usage factor inside the line set ij and ik linked in power system between the bus- i and bus- j. The algorithm of DLUF implementation:

1. Calculate the data in bus and data in line by performing flow of power with load analysis.
2. Estimate the values of LUF within the lines.
3. Estimate the line DLUF for highest ranking with power congestion within lines connection.
4. Placement of IPFC with value of DLUF highest within lines.
5. To calculate power flow analysis with IPFC controller for estimation of LUF in the transmission lines.

4. IPFC Optimal Tuning

A goal is to estimate the appropriate size of the IPFC to minimize watt power loss, total voltage variations, and the optimization of the security edge using the minimal IPFC parameter implemented. The formula as listed below is used to minimize the multi-target function (6).
F = W₁X Active power loss + W₂X Voltage deviation + W₃X Security margin + W₄X IPFC size \hspace{1cm} (6)

W₁, W₂, W₃, W₄ are weighting factors.

\[ W₁ + W₂ + W₃ + W₄ = 1 \]  \hspace{1cm} (7)

\[ W₁ = W₂ = W₃ = W₄ = 0.25 \]

Equation is hinged to reduce the active loss of electricity \hspace{1cm} (8).

\[
P_{\text{loss}} = \left| V_i \right|^2 G_{\text{in}} - \left| V_i \right| \left| V_n \right| \left| G_{\text{in}} \cos \theta_{\text{in}} + B_{\text{in}} \sin \theta_{\text{in}} \right| - \left| V_i \right| \left| V_{\text{se}_{\text{in}}} \right| \left| G_{\text{in}} \cos \theta_{\text{se}_{\text{in}}} + B_{\text{in}} \sin \theta_{\text{se}_{\text{in}}} \right|
\]

\[ + \left| V_n \right|^2 G_{\text{in}} - \left| V_i \right| \left| V_n \right| \left| G_{\text{in}} \cos \theta_{\text{n}_{\text{i}}} + B_{\text{n}} \sin \theta_{\text{n}_{\text{i}}} \right| \left| V_{\text{se}_{\text{n}}} \right| \left| G_{\text{in}} \cos \theta_{\text{se}_{\text{n}}} + B_{\text{n}} \sin \theta_{\text{se}_{\text{n}}} \right| \]

\hspace{1cm} (8)

Equation (9) may represent the voltage deviation

\[ VD = \sum_{k=1}^{N\text{bus}} \left| V_k - V_k^{\text{ref}} \right|^2 \]  \hspace{1cm} (9)

\[ V_k \] is the voltage magnitude a bus k

The safety rate of a critical state system may be stated in equation as follows \hspace{1cm} (10)

\[ S_M = \frac{\sum_{j \in J_L} S_{ij}^{\text{lim}} - \sum_{j \in J_L} S_{ij}^{\text{initial}}}{\sum_{j \in J_L} S_{ij}^{\text{lim}}} \]  \hspace{1cm} (10)

\[ J_L = \text{A set where all bus loads are contained} \]

For a system with typical operating conditions, SM takes a value from zero to one. The goal function of equation (10) is transformed as equation as it is meant to minimize the function \hspace{1cm} (11).

\[ -SM = \frac{\sum_{j \in J_L} S_{ij}^{\text{initial}}}{\sum_{j \in J_L} S_{ij}^{\text{lim}}} \]  \hspace{1cm} (11)

To resolve the overload on the transmission lines as equation, the size of the installed IPFC is necessary \hspace{1cm} (12).

\[ \sum_{i} P_{Q_1}^2 + \sum_{i} P_{Q_2}^2 = \left( V_{\text{se}_{ij}} \left( \frac{V_i - V_{\text{se}_{ij}}}{Z_{ij}} \right) \right)^2 + \left( V_{\text{se}_{ik}} \left( \frac{V_i - V_{\text{se}_{ik}}}{Z_{ij}} \right) \right)^2 \]  \hspace{1cm} (12)

\[ \text{PQ: IPFC VSCs each size} \]

Equality Constraints

\[ P_{gi} + P_{Di} = \sum_{n=1}^{j} V_i V_n \cos(\theta_{\text{in}} + \theta_{n} - \theta_{i}) \forall i \]  \hspace{1cm} (13)

\[ Q_{gi} + Q_{Di} = \sum_{n=1}^{j} V_i V_n \sin(\theta_{\text{in}} + \theta_{n} - \theta_{i}) \forall i \]  \hspace{1cm} (14)

Inequality Constraints

\[ V_i^{\text{min}} \leq V_i \leq V_i^{\text{max}} \forall i \in \text{loadbus} \]  \hspace{1cm} (15)

\[ S_{ij}(\theta, \delta) \leq S_{ij}^{\text{max}} \]  \hspace{1cm} (16)
**IPFC Constraints**

\[
V_{se}^{\text{min}} \leq V_{se} \leq V_{se}^{\text{max}} \\
\theta_{se}^{\text{min}} \leq \theta_{se} \leq \theta_{se}^{\text{max}}
\]  
(17)  
(18)

**4.1 Gravitational Search Algorithm**

A new method hinged on the Newton's Gravity statement is a Gravitational Search algorithm. Masses tending towards each other are to accelerate, which is known as gravity. Most objects attract one another with the strength of gravitational strength, including the strength which is global movement towards heavy-mass objects. In the GSA, agents are recognized by their individual masses as objects that assess their performance. Therefore, masses, through gravity, have a direct method of communication. The masses are heavier compared to the light ones with the superior solution and mobility.

Four characteristics include: inertial weight, location, gravitate active weight and passive weight in each mass (agent). The mass position relates to the solution to a problem and the fitness function determines its gravitational and inertial masses. The location of each mass is regarded as optimal and the technique changes the mass of gravity and inertia to provide a better answer. The GSA algorithm may be seen as an artificial universe of masses that obey the Newtonian gravity and motion rules. Figure 1 mentions GSA Application to Optimal Tuning of IPFC. By the time span masses are drawn by the larger mass, which is the ideal solution in the optimization algorithm search area. Refer to [17] for full mathematical equations.

![Fig 1 Objective Function Value for various Gravity Search Algorithm parameter settings](image1)

![Fig 2 Target Function Value for N=50 Gravitational Search Algorithm parameter setting](image2)
4.2 Particle Swarm optimization:

Both Eberhart and Kennedy have described PSO as a quick, simple and effective optimization technique based on the population [3]. Each particle changes its location dependent on its best location, best world location among the particles and its previous vector speed: The following equations apply:

\[
v_{i}^{k+1} = w X v_{i}^{k} + c_1 X r_1(p_{best_i} - x_{i}^{k}) + c_2 X r_2(g_{best} - x_{i}^{k})
\]  
(19)

\[
x_{i}^{k+1} = x_{i}^{k} + \chi X v_{i}^{k+1}
\]  
(20)

where,

- \(v_{i}^{k+1}\): The velocity of \(i^{th}\) spot at \((k+1)^{th}\) iteration
- \(w\): Inertia weight of the particle
- \(v_{i}^{k}\): The velocity of \(i^{th}\) spot at \(k^{th}\) iteration
- \(c_1, c_2\): Positive constants having values between \([0, 2.5]\)
- \(r_1, r_2\): Randomly generated numbers between \([0, 1]\)
- \(p_{best_i}\): The finest location of the \(i^{th}\) particle calculated hinged upon its own experience
- \(g_{best}\): Global finest location of the particle in the population
- \(x_{i}^{k+1}\): The location of \(i^{th}\) spot at \((k+1)^{th}\) iteration
- \(x_{i}^{k}\): The location of \(i^{th}\) spot at \(k^{th}\) iteration
- \(\chi\): Constriction factor. It may help insure convergence.

Acceptable choice of inertia weight \(w\) provides good balance between global and local explorations.

\[
w = w_{max} - \frac{w_{max} - w_{min}}{iter_{max}} X iter
\]  
(21)

When, at the beginning of the iteration, the value of the inertia is the value of the inertia weight at the end, the current number of iterations and the upper bound.

**Step by step procedure for IEEE 30 bus tests system using PSO:**

1. Set the control variables within the acceptable range \((vg1, vg2, vg5, vg8, vg11, vg13, T1, T2, T3, T4, QC3, QC10 and QC24)\), set population size (=200), assume appropriate PSO values; enter the data for the 9 bus tests;
2. Grasp iter=0
3. Create the population of spots and their velocities at random.
4. For each particle, run the NR load flow to determine losses.
5. compute the fitness function of each spot
6. Find out “personal best (Pbest)” of all spots and “global best(Gbest)” particle from their fitnesses
7. iter=iter+1
8. Obtain the velocity of each spot hingedequ. (19) and adjust it if its limit gets violated
9. Determine the new position of each particle hingedequ. (20)
10. To obtain losses, run the NR load flow for each spot.
11. Obtain the fitness function of each particle using equ
12. If current fitness (P) is greater than Pbest for each spot, then Pbest=P.
13. Pbest’s finest should be set as Gbest’s finest.
14. Continue until step 7 until the large number of iterations is reached.
15. The coordinate of the Gbest particle provides optimal values for control variables, while its fitness provides a low value for losses.

**Simulation Results:**

Elapsed time is 0.939709 seconds.
## Power Flow Solution

| Bus No. | Load | Generation | Injected |
|---------|------|------------|----------|
|         | MW   | Mvar       | MW       | Mvar    | MW       | Mvar    |
| 1       | 0.000| 0.000      | 260.998  | -17.021 | 0.000    |
| 2       | 21.700| 12.700     | 40.000   | 48.822  | 0.000    |
| 3       | 2.400| 1.200      | 0.000    | 0.000   | 0.000    |
| 4       | 7.600| 1.600      | 0.000    | 0.000   | 0.000    |
| 5       | 94.200| 19.000     | 0.000    | 35.975  | 0.000    |
| 6       | 0.000| 0.000      | 0.000    | 0.000   | 0.000    |
| 7       | 22.800| 10.900     | 0.000    | 0.000   | 0.000    |
| 8       | 30.000| 30.000     | 0.000    | 30.826  | 0.000    |
| 9       | 0.000| 0.000      | 0.000    | 0.000   | 0.000    |
| 10      | 5.800| 2.000      | 0.000    | 0.000   | 19.000   |
| 11      | 0.000| 0.000      | 0.000    | 0.000   | 16.119   |
| 12      | 11.200| 7.500      | 0.000    | 0.000   | 0.000    |
| 13      | 0.000| 0.000      | 0.000    | 10.423  | 0.000    |
| 14      | 6.200| 1.600      | 0.000    | 0.000   | 0.000    |
| 15      | 8.200| 2.500      | 0.000    | 0.000   | 0.000    |
| 16      | 3.500| 1.800      | 0.000    | 0.000   | 0.000    |
| 17      | 9.000| 5.800      | 0.000    | 0.000   | 0.000    |
| 18      | 3.200| 0.900      | 0.000    | 0.000   | 0.000    |
| 19      | 9.500| 3.400      | 0.000    | 0.000   | 0.000    |
| 20      | 2.200| 0.700      | 0.000    | 0.000   | 0.000    |
| 21      | 17.500| 11.200     | 0.000    | 0.000   | 0.000    |
| 22      | 0.000| 0.000      | 0.000    | 0.000   | 0.000    |
| 23      | 3.200| 1.600      | 0.000    | 0.000   | 0.000    |
| 24      | 8.700| 6.700      | 0.000    | 0.000   | 4.300    |
| 25      | 0.000| 0.000      | 0.000    | 0.000   | 0.000    |
| 26      | 3.500| 2.300      | 0.000    | 0.000   | 0.000    |
| 27      | 0.000| 0.000      | 0.000    | 0.000   | 0.000    |
| 28      | 0.000| 0.000      | 0.000    | 0.000   | 0.000    |
| 29      | 2.400| 0.900      | 0.000    | 0.000   | 0.000    |
| 30      | 10.600| 1.900      | 0.000    | 0.000   | 0.000    |

Total: 283.400 126.200 300.998 125.144 23.300

Table 1: losses with and without optimization

| SlNo. | Losses devoid of optimization | Losses with optimization |
|-------|------------------------------|--------------------------|
| 1     | 25.73 MW                      | 24.308 (fxmin)           |
| 2     | 137.56 MVAR                   | 134.10                   |
Table 2: Control variable values with optimization

| Bus | Control variables | Optimized values (x_{min}) |
|-----|-------------------|----------------------------|
| 1   | Vg1 (pu)          | 1.082                      |
| 2   | Vg2               | 1.043                      |
| 5   | Vg5               | 1.044                      |
| 8   | Vg8               | 1.041                      |
| 11  | Vg11              | 1.090                      |
| 13  | Vg13              | 1.056                      |
| 9-6 | T1                | 0.969                      |
| 10-6| T2                | 1.015                      |
| 12-4| T3                | 1.033                      |
| 28-27| T4              | 0.982                      |
| 3   | QC3 (MVAR)        | 10.778                     |
| 10  | QC10              | 7.549                      |
| 24  | QC24              | 11.750                     |

Table 3: Selected parameters of PSO

|   | Description                                      | Value       |
|---|--------------------------------------------------|-------------|
| 1 | Size of population                              | 50          |
| 2 | Acceleration constant (C1,C2)                   | 1.4 & 1.4   |
| 3 | Constriction factor                             | 0.729       |
| 4 | Maximum inertia & Minimum inertia               | 0.90 & 0.40 |
| 5 | Maximum velocity & Minimum velocity             | 0.003 & -0.003 |
| 6 | Convergence criterion                           | 200 iteration |

Fig. 3: Convergence characteristic of PSO

Fig 4: Comparison of NR conventional Method and PSO
Table 4. Combined Result of Optimization algorithms (GSA and PSO)

| SL No. | Losses before optimization | Losses after optimization (GSA) | Losses after optimization (PSO) |
|--------|----------------------------|---------------------------------|--------------------------------|
| 1      | Active power losses (P\textsubscript{loss}) MW | 25.73                           | 24.308                          | 25.53                          |
| 2      | Reactive power losses (Q\textsubscript{loss}) MVAR | 137.56                          | 134.10                          | 141.12                          |

4.3 Artificial Intelligent Controllers:
The controller with PID variables calculates the values of the PID, i.e., proportional, integral and derivative, using the Ziegler-Nicolas algorithm which contains separate parameters of three in number. The gain parameter of proportional controller which estimates the error obtained, the parameters of Integral estimate the result which rely on the accumulation of errors, Derivative of the parameters which estimates result obtained on proportionate rate with the error which fluctuates constantly. In total, three gain actions are utilized to alter the process by means of the control components.

\[
MV(t) = P_{out} + I_{out} + D_{out}(22) \\
u(t) = MV(t) = K_p e(t) + K_i \int_0^t e(\tau)d\tau + K_d \frac{de}{dt}(23)
\]

Three variables like $P_{out}$, $I_{out}$, and $D_{out}$ are standard tuned variables to calculate better response of the PID controller.

4.4 Fuzzy Logic Controller
A pre-initiative approach is Fuzzy logic system that enhances the traditional engineering system control paradigm. Use of artificial intelligence methods that help primarily to mathematically model rigorously. Controller i.e., fuzzy logic is a large extent of traditional logical truth, and fluorescent logic controllers are an accurate linear extension of control models.
The typical basic problem in Fuzzy Inference System (FIS) is the graphical user interface (GUI) program using Fuzzy Logic Toolbox in MATLAB software.

Table 5: Fuzzy logic Rule table

| e   | NL | NM | NS | ZE | PS | PM | PL |
|-----|----|----|----|----|----|----|----|
| de  | NL | NL | NL | NL | NM | NS | ZE |
| NL  | NL | NL | NL | NL | NM | NS | ZE |
| NM  | NL | NL | NM | NS | ZE | PS | PM |
| NS  | NL | NL | NM | NS | ZE | PS | PM |
| ZE  | NL | NM | NS | ZE | PS | PM | PL |
| PS  | NM | NS | ZE | PS | PM | PL | PL |
| PM  | NS | ZE | PS | PM | PL | PL | PL |
| PL  | NL | NS | ZE | PS | PM | PL | PL |

4.5 Neural Networks

Parallel to the operations are neural networks with simple components. Systems inspire the aspects of biological nervousness. The network function is usually determined by connecting components. A neural network in particular is trained by changing the data between weights and output to fulfill a function. The data are taken into account within the limits. The input and output couples for the common neural networks are trained to enhance the system better by altering the weight gains.

![Neural Network diagram - Back Propagation](image)

Table 6. Combined Results obtained from Artificial Intelligent Controllers (PI, FLC and NN controllers) for Real Power Loss

|       | Without Controller | With PI Controller | With FLC Controller | With NN Controller | With GSA Algorithm |
|-------|--------------------|--------------------|---------------------|-------------------|-------------------|
| M -1  | 28                 | 18                 | 16.87               | 19.5              | 21.654            |
| M - 2 | 21                 | 15.2               | 14.42               | 7.48              | 26.697            |
| M - 3 | 23                 | 12                 | 10.65               | 23.76             | 32.022            |

Table 7. Combined Results obtained from Artificial Intelligent Controllers (PI, FLC and NN controllers) for Reactive Power Loss

|       | Without Controller | With PI Controller | With FLC Controller | With NN Controller | With GSA Algorithm |
|-------|--------------------|--------------------|---------------------|-------------------|-------------------|
| M - 1 | 107.278            | 101.103            | 99.81               | 100.26            | 100.867           |
| M - 2 | 127.724            | 119.081            | 102.65              | 105.12            | 118.518           |
| M - 3 | 160.339            | 149.040            | 124.31              | 132.020           | 149.273           |

5. Analysis

In the first model, the fault occurs near generator 1. In the 2nd model, failure takes place near generator 2. The problem occurs near generator 3 in the third model. A set of fuzzy rules was also
used to construct the control approach. The fuzzy control strategy was created on the basis of the standard IPFC controller and was placed prior to the IPFC in the modelling. The main benefit of modelling the fuzzy coordination controller before the IPFC is that the amplification part of the conventional controller is modified by the fuzzy coordination unit, increasing power system stability. The simulations were conducted in MATLAB R 2015a Version, and the results were shown on the scope. For all three models, graphs of power angle vs. time were seen with and devoid of the controller. The efficacy of Fuzzy based IPFC coordination ideas in damping power system oscillations above the effectiveness of Fuzzy based IPFC coordination concepts in damping network system oscillations devoid of the Fuzzy based IPFC coordination scheme.

6. Results and Discussion
The methodology of load flow with IEEE 30 node system proposed for which is estimated in MATLAB Software for obtaining results. For placement of IPFC which includes load buses in IEEE buses. Weights of 0.25 have the same value and can be used with any purpose. The analysis and findings under the conditions of standard loading, 110 percent loading and 125 percent loading. The LUF parameters comparing transmission lines with and without appropriate IPFC positioning.

LUF levels for overloaded lines should be minimized, whereas LUF values for underused lines should be increased. The suggested technique lowers the congestion inside the lines to a large amount when the IPFC is placed and tuned. Table 3 shows the IPFC parameters for the various loads studied. The loss in watt and wottles power of a power system with and without an IPFC controller, adjusted and untuned using various optimization approaches and loads. As a result, there is a power redistribution that includes power flow in the system due to the location of the IPFC. The suggested approach includes testing under standard load, 110 percent load, and 125 percent loading conditions. The tuning and placement of IPFC using the suggested approach for minimizing losses in the power system under normal and severe load situations.

Reducing actual and reactive power losses while improving power transfer capabilities. The reactive power loss of the system has been evaluated with and without IPFC, with optimal IPFC location, and with optimally adjusted IPFC for different loads. Voltage deviation can be reduced by decreasing voltage instability. Loss reduction as a result of reduced congestion in the power system, maximizing the security margin safeguards the system against collapse. Optimal tuning using a FACTS device, such as an IPFC, utilizing the Gravitational Search method, which incorporates voltage deviation, reduces system loss while maximizing security margin with the use of a small IPFC. The device’s cost is reduced when the IPFC’s size is reduced. As a result, total network performance has been increased at a low cost.

7. Conclusion
The reduction of transmission line congestion is a critical topic that is addressed in this paper:
• For congestion control, the optimal location of IPFC is found using the Disparity Line Utilization Factor. The use of DLUF for IPFC placement, which efficiently decreases line congestion and power loss.
• A multi-objective function consisting of minimizing overall voltage deviations, reducing active power loss, and maximizing security margin with the least amount of installed IPFC evaluated for IPFC optimum tuning utilizing the Gravitational Search algorithm.
• For the IEEE-30 node test system, the GSA parameter for IPFC adjustment is implemented in MATLAB software.
• The findings were presented and analyzed under loading conditions in order to determine the efficacy of the suggested approach on power system performance.
The efficiency and accuracy of simulation results in terms of Gravitational Search algorithm approach are required to accomplish the numerous objectives for finding the best IPFC settings under varied loading situations.

For the installed IPFC, reductions in actual power loss, voltage variation, and size have been accomplished, along with an increase in the system's security margin. After adjusting the IPFC device, the watt and wattles power loss in the distribution network is reduced by roughly 6%. The lesser in loss aids in the network's congestion management. Increased security edge safeguards the system against collapse. The device's installation cost is reduced when the IPFC size is reduced. As a result, total network performance has been increased at a low price.

8. Future Scope

- Real-time loading and contingency studies can be used to further assess IPFC's efficacy under unfavourable conditions.
- A multi-objective function consisting of active power loss reduction, IPFC deployment utilizing DLUF efficiently lowers line congestion and power loss. The optimal tuning of IPFC takes into account the reduction of total voltage variations and maximizing of security margin with the use of the smallest value of installed IPFC.

References

[1] Abdel-Moamen, M.A and N. P. Padhy, "Optimal power flow incorporating FACTS devices bibliography and survey," in Proc. 2003 IEEE PES Transmission and Distribution Conference and Exposition, pp. 669-676

[2] Ashwani Kumara, S.C. Srivastava, S.N. Singh, “Congestion management in competitive power market: A bibliographical survey”, Electric Power Systems Research 76, 153–164, May 2005.

[3] A. Mishra, G. V. Nagesh Kumar, "A Redundancy Based Optimal Placement of Interline Power Flow Controller Using Composite Severity Index for Contingency Management”, Periodica Polytechnica Electrical Engineering and Computer Science, 59(4), pp. 138-146, 2015.

[4] S.N. Singh, A.K. David, “Optimal location of FACTS devices for congestion management”, Electric Power Syst. Res. 58, 71–79, June 2001.

[5] H. Besharat, and S.A. Taher, “Congestion management by determining optimal location of TCSC in deregulated power systems”, Electrical Power and Energy Systems 30, 563–568, June 2008.

[6] M. Mandala, and C.P. Gupta, “Congestion management by optimal placement of FACTS device”, PEDES and Power India, 2010, pp. 1-7, New Delhi, India

[7] R. Minguez, F.Milano, R Zarate-Minano, A.J. Conejo, “Optimal Network Placement of SVC Devices”, IEEE Trans. On Power Systems, Vol.22, No.4, Nov.2007.

[8] S.S. Reddy, M.S.Kumari and M. Sydulu, “Congestion management in deregulated power system by optimal choice and allocation of FACTS controllers using multi-objective genetic algorithm”, Transmission and Distribution Conference and Exposition, IEEEPES, pp. 1-7, April 2010.

[9] N. Acharya, N. Mithulananthan, “Locating series FACTS devices for congestion management in deregulated electricity markets”, Electric Power Systems Research, Volume 77, Issues 3–4, March 2007, Pages 352–360

[10] N. G. Hingorani and L. Gyugyi, “Understanding FACTS: Concepts and Technology of Flexible AC Transmission System”, IEEE Press, 2000.
[11] J. Zhang, “Optimal Power Flow Control for Congestion Management by Interline Power Flow Controller (IPFC)” International Conference on Power System Technology 2006, Chongqing, China, 2006, pp. 1-6.

[12] Teerthana S., Yokoyama A., “An Optimal Power Flow Control Method of Power System using Interline Power Flow Controller (IPFC)” TENCON 2004, Nov. 2004, pp. 343-346.

[13] A. Kargarian, B. Falahati,” Multiobjective Optimal Power Flow Algorithm to Enhance Multi-Microgrids Performance Incorporating IPFC” IEEE Power and Energy Society 2012, Sandiego, CA, Pp. 1-6.