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Voltage Stability Enhancement with Optimal Placement of IPFC

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Abstract*: This paper presents a novel technique based on Cuckoo Search Algorithm (CSA) for enhancing the performance of multiline transmission network to reduce congestion in transmission line to huge level. Optimal location selection of IPFC is done using subtracting line utilization factor (SLUF) and CSA-based optimal tuning. The multi objective function consists of real power loss, security margin, bus voltage limit violation and capacity of installed IPFC. The multi objective function is tuned by CSA and the optimal location for minimizing transmission line congestion is obtained. The simulation is performed using MATLAB for IEEE 30-bus test system. The performance of CSA has been considered for various loading conditions. Results shows that the proposed CSA technique performs better by optimal location of IPFC while maintaining power system performance.

***Keywords* : Interline power flow controller (IPFC); optimal location; subtracting line utilization factor, voltage stability, FACTS controller, IPFC.**

I. INTRODUCTION

There is a massive enhancement in power transaction due to power system renovation and different factors such as environmental, economical and right-of-way which forms the hurdle for the expansion of power transmission network. With the improvement in flexible Ac transmission system (FACTS), several innovative concepts turn the system into more flexible and have control over power flow without altering the generation schedule. Optimal location identification and allocation of FACT components addresses operating parameters of the plant [1], [2]. FACTs devices are designed based on power electronics and other stationary tools which control many quantities of AC transmission system and by enhancing the controllability and surge impedance loading [3]. Different facts components can be used for this resolution such as SVC, STATCOM, SSSC, TCSC, UPFC and IPFC [4].

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IPFC consists of more FACTS controllers in series and it controls power flow for set of transmission lines and sub-transmission networks. On the other hand the UPFC controls power flow in only one transmission line. The IPF Controller able to transfer active power directly among the compensated lines and shifts the load demand from heavily loaded to lightly loaded transmission lines [5],

the change between transmission lines utilization (SLUF) is considered and it provides the alteration in the fraction of line being utilized for transmission of power. It addresses the fraction of error in transmission line used for flow of power. All transmission lines must be ranked in decreasing order according to transmission line utilization factor. Transmission line having the top rank is assumed as the utmost congested line. SLUF is determined for all transmission lines interconnected with utmost congestion line. Each Line pair which is linked to the same bus is graded according to SLUF. The line with maximum value of SLUF is assumed as the optimum position of IPFC for bottleneck managing. No generalized approach is available for placing any FACT devices. Number of methods has been formalized for finding the optimal location for a particular type of FACT device.

In this paper, the optimal sizing of IPFC is estimated by subtracting LUFs between two lines and the line pairs are ranked based on congestion and the priority has been allotted. The optimal placing of IPFC is carried out by cuckoo search algorithm (CSA), section II describes the modeling of IPFC; section III describes cuckoo search (cs) algorithm, section IV explains about optimal allocation of IPFC, section V demonstrates the plenary results and lastly, discussion on conclusion is mentioned with Section VI.

II. IPFC MODELLING

Schematic arrangement of IPFC is shown in Fig.1. Back to back DC to AC converters are connected through common DC link represented as the bidirectional link, for exchanging of active power between them [6,7]. The buses L,M and N has the complex voltages V_L, V_M and $V_{N.}$ $V_{SE\ Li}$ is series converter voltage and it is the controllable voltage source which is injected in series and can be noted as $V_{Se\ Li} = V_{Se\ Li} \angle \theta_{Se\ Li}$ (i=M,N).

Bus M is connected to bus L and bus N is also connected to bus L. Equivalent circuit of IPFC is shown in Fig.2.

Series injected voltages are $V_{SE\ Li}$ (i=M, N)

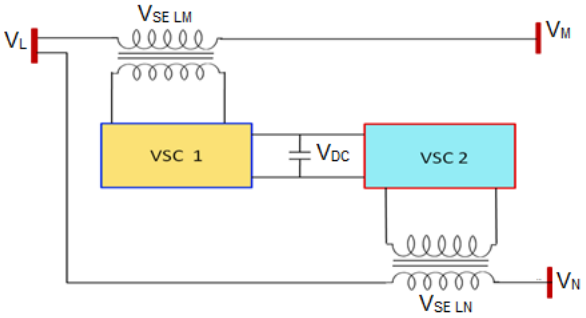


Fig 1. Basic schematic of IPFC.

III. OPTIMAL SIZING OF IPFC

The optimal sizing of IPFC minimizes load voltage deviation (LVD), active power loss and installed capacity of IPFC. Optimal sizing is determined by formulating an objective function.

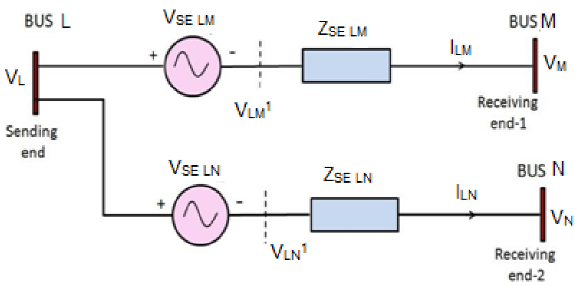


Fig. 2. IPFC equivalent circuit.

The active and reactive power of transmission line1 are

$$P_{Li}^{1} = -b_1 V_L V_{SELM} COS(90-\theta_{SELM}+\theta_L) - b_1 V_M V_L COS(90+\theta_L-\theta_M) \quad (1)$$

$$Q_{Li}^{1} = b_1 V_L^2 - b_1 V_L V_{SELM} COS(90-\theta_{SELM}+\theta_L) - b_1 V_M V_L COS(90+\theta_L-\theta_M) \quad (2)$$

The real and reactive powers of line2 are

$$P_{Li}^{1} = -b_2 V_L V_{SELN} COS(90-\theta_{SELN}+\theta_L) - b_2 V_N V_M COS(90+\theta_L-\theta_N) \quad (3)$$

$$Q_{Li}^{2} = b_2 V_L^2 - b_2 V_L V_{SELN} COS(90-\theta_{SELN}+\theta_L) - b_2 V_N V_L COS(90+\theta_L-\theta_N) \quad (4)$$

The real power injected by converter1 is given by

$$P_{SELM} = \mathrm{Re}[S_{SELM}] = -b_1 V_L V_{SELM} COS(90-\theta_L+\theta_{SELM}) + b_1 V_{SELM} V_M COS(90-\theta_M+\theta_{SELM}) \quad (5)$$

Converter1 reactive power injection is given by,

$$Q_{SELM} = \mathrm{Im}[S_{SELM}] = -b_1 V_L V_{SELM} SIN(90-\theta_L+\theta_{SELM}) + b_1 V_{SELM}^2 + b_1 V_{SELM} V_M COS(90-\theta_M+\theta_{SELM}) \quad (6)$$

Converter2 real and reactive power injections are given by:

$$P_{SELN} = \mathrm{Re}[S_{SELN}] = -b_2 V_L V_{SELN} COS(90-\theta_L+\theta_{SELN}) + b_2 V_{SELN} V_N COS(90-\theta_N+\theta_{SELN}) \quad (7)$$

$$Q_{SELN} = \mathrm{Im}[S_{SELN}] = -b_2 V_L V_{SELN} SIN(90-\theta_L+\theta_{SELN}) + b_2 V_{SELN}^2 + b_2 V_{SELN} V_N COS(90-\theta_N+\theta_{SELN}) \quad (8)$$

In order to find the optimum location for placing IPFC units a number of methods are developed. This paper presents a technique based on Subtracting Line Utilization Factor (SLUF) is developed and utilized in optimal sizing of IPFC.

A. Subtracting Line Utilization Factor(SLUF)

Transmission line congestion can be determined with the help of Line Utilization Factor index. LUF is given as,

$$LUF = \frac{MVA_{ij}}{MVA_{ij\,\max}}$$

Here LU F_{ij} -- Line Utilization Factor of transmission line between bus i and bus j.

M V $A_{ij\,\max}$ -- Maximum mega volt ampere rating of transmission line connected between bus i and bus j.

M V A_{ij} - Actual mega volt ampere rating of transmission connected between bus i and bus j.

Line utilization factor always provides an estimation of the fraction of line actually utilized. It is an effective technique in determining the congestion of a transmission line. To evaluate the performance of a system by incorporating IPFC, needs at smallest two transmission lines which are linked to a common bus. Thus, Line utilization factor index is only not enough for the incorporation of IPFC.

Therefore, a new index Subtracting Line Utilization Factor is suggested for optimal location of IPFC. Subtracting line utilization factor specifies the transformation between the utilization of the lines. Hence SLUF gives an assessment of the difference of fraction of transmission line being used for power flow.

Each transmission line is initially in the order of descending according to their LUFs. Transmission line which is top ranked is assigned as the utmost congested line. For all the lines which are directly linked to the highest congestion line, SLUF is measured. Based on SLUF ranking is given to all pairs of the lines which are directly associated to the same bus.

The transmission line which is having maximum value of SLUF is taken as optimal place of IPFC for Bottleneck Management.

Here assumption is that both the lines should have same rating:

$$SLUF_{ij-ik} = \frac{MVA_{ij} - MVA_{ik}}{MVA_{\max}}$$

Where SLU F_{ij-ik} - Subtracting Line Utilization Factor (SLUF) of transmission lines ij and ik,

MVA_{ij} -- MVA rating of the transmission line connected among buses i and j

MVA_{max} -- Maximum mva rating of transmission line
MVA_{ik} – Actual MVA rating of transmission line which is linked between bus i and bus k.

B. Cuckoo Search (CS) Algorithm

Global optimization method proposed by Yang & Deb (2009) according to the nature of cuckoos. The innovative "cuckoo search (CS) algorithm"[8] is developed on the following conditions:-

1) Where Cuckoos in the host nests lay their eggs
2) How, when identified and killed, the host hatches the eggs to the chicks.
3) How to use an algorithm which is based on a system to find a function's overall optimization.

The CS was influenced by some cuckoo species obligatory family parasitism with placing their eggs in host birds nest. Many cuckoos have evolved to mimic the colours and shapes of the eggs of a few selected host types through female parasite cuckoos.

This helps in reduction of the likelihood of abandoning eggs and there by productivity increases.

If host cuckoos notice that the eggs present are not their eggs, then they resolve that issue either by throwing them away or just give up those nests and construct new ones.

Dependent cuckoos frequently select a nest where their o wn eggs were just laid by the host bird.

The cuckoo eggs are usually hatching slightly earlier than their host eggs. If the first cuckoo baby bird is hatched, then the first instinctual act is to eject host eggs by instinctively pushing the eggs out of the nest once the very first cuckoo baby bird is hatched. This behavior leads to an increase in the part of food providing by the host bird which will be fed to the cuckoo chick.

In addition, studies show a cuckoo chick may imitate the h ost chick's call to increase access to more feeding opportunit ies.

every egg in a nest signifies a clarification, and a cuckoo egg correspond to a new resolution. Every egg in a nest signifies a clarification & Cuckoo egg corresponds to different resolution.

Aspire is to use the innovative and potentially improved r esolutions.

The procedure can be generalized to further complex cases where each and every nest has several eggs that represents a set of solution.

C. EXECUTION and STRENGTH FUNCTION

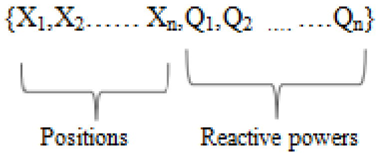
1.Resolution vector:

Resolution to the problem is 2n elemental vector; with n as number of IPFC devices.

IPFC system positions are the first n elements. Every element is a natural number representing the no. of the bus connected to an IPFC system.

The other elements are continuous values that reflect IPFC d evices ' optimally mounted reactive energy.

Figure shows a solution vector's structure.



It can lead the search engine to duplicated solutions with the above solution structure.

In addition, two solutions give the same result that we need t o install IPFC with the same amount of injected reactive power on two buses { 12 and 14}.

In order to avoid this scenario, we have suggested another limitation on IPFC positions as

$$x1 < x2 < ... < xn.$$

2. Overall procedure:

Following are the procedural steps in implementing CSA algorithm for optimal

Location and size of IPFC:

Step1:Select control parameters for CSA algorithm, like pro bability of cuckoo eggs being identified, the no. of nests is NP and Itmax is no. of iterations.

Step2: Creating current Nests with random initial nests.

Step3: Assess the fitness function value FF, Calculating the power flow using the Newton-Raphson load flow technique.

Step4:Find the fitness function's best value FF the good and the best Nest. Set the counter for iteration k = 1.

Step5:

Generate new Nests of Cuckoos eggs by Le'vy flight,[9] and new nests.

Step 6: Adapt eggs which infringe constraints of IPFC device & limit number of buses.

Step 7: Assess FF new which is new nests strength function.

Step8: To choose the better nests, compare FFnew values with the existing FF values. Review the current nest, the best fitness feature value for FFbest for best nest.

Step 9: Identification of cuckoo eggs by casual partial walks build new Nests.

Step 10: Adjust the eggs that infringe constraints of the IPFC system &limit the no. of buses.

Step11:Assess FFnew the fitness feature for new Nests once again.

Step12: Edit fitness function values for the current nest FF and fitness function best value FFbest.

Step13:Check for the counter of iteration k is less than Itmax i.e the maximum iterations & if so, increment k to the next value and return to step 5. Else Stop the process.

3. Overview of CSA

By placing their eggs in the nests of the host birds, CSA Forces brood parasitism of cuckoo species. CSA is a stochastic global, population-based search meta-heuristics. This algorithm is a mixture of some birds ' Levy flight behavior[9] and inspired us to measure location and other p arameters including overloaded lines, voltage breach limit an d IPFC congestion management.

CSA follows three important rules:

1) each cuckoo can randomly select the location and lay its e ggs one at a time.

2) The Elitist selection process establishes the highest quality eggs present in their nest and transfers them to the next generation.

3)The number of the host nest can not be adjusted and the egg laid by the cuckoo can be based on the probability suggested in[10] by $P_d \varepsilon(0,1)$

At first, the objective function value Fi(x) for the i-th population is

$\forall_i = 1,2,...,n. \quad F_i(x) = f(x_{1i}, x_{2i}, x_{3i}, ..., x_{ni}),$

n indicates the no. of control variables & m represents the total no. of populations.

The population size of the individual control variable can be generated randomly as:

$$x_{ij} = x_j^{min} + rand(0,1) \times \left(x_j^{max} - x_j^{min}\right) \qquad (9)$$

Here i indicates the no. of host nests; i=1,2,3,....,n and j indicates the no.r of control variables; j=1,2,3,...,m.

x_j^{min} represents the lower limit of j[th] control variable and x_j^{max} represents the upper limit of j[th] control variable. respectively.

Rand(0,1) is distributed uniformly and the parameter Estimation solution is feasible because it is initialized within the feasible range and the optimal one has to be found.

Levy flight is conducted to generate new solutions [23].

We chose a simple scheme to measure the position and set certain IPFC parameters where each nest has only one egg.

The Cuckoo, K uses the following formula to generate a n ew solution using Levy flight:

$$x_i(k+1) = x_i(k) + SZ_{ij} \times \beta \oplus levy(\lambda) \qquad (10)$$

Where SZ_{ij} is the step size is calculated as $SZ_{ij} = SZ_{ij}^t - SZ_{fj}^t$,

β is the step size and we assume the step size is 1.

Equation (10) shows that the stochastic equation for random walk.

Random walk is based on Markov chain and its next status be subject to the existing location and the transition probability.

CSA has high speed of convergence compared to other optimization techniques .

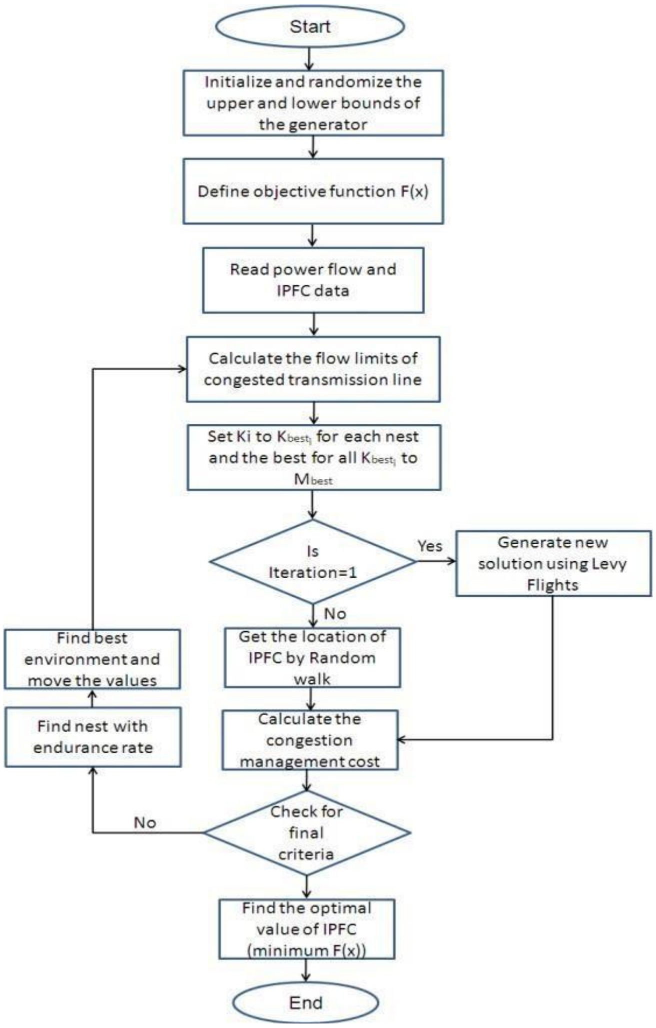


Fig.3. Flow chart of the implemented CSA algorithm

IV. OPTIMAL ALLOCATION OF IPFC

A large scale of distributed network with 30 nodes is cons idered to illustrate the efficiency of the proposed CSA techni que. The initial minimum bus voltage was 0.95 p.u and total load power is 21953.4W. The series inductive reactance is 2.73% p.u. The coupled pi-section inductive reactance is 5.79% p.u, the susceptance is 5.62% p.u, and resistance is 1.89% p.u. The series coupling transformer rating 30.32 MVA with leakage reactance is 1.0% p.u, and has a winding ratio of 22.73 kV/9.21 kV.

1) A.Step by StepProcedure:

Step I: Read line data and bus data.

Step II: Calculate power flow in all the lines and determine LUFS.

Step III: Calculate SLUFs of all the lines in accordance with highest congestion rating transmissi on lines.

Step IV: Place IPFC on the line with highest SLUF value.

StepV: Analyze the load stream and measure all lines of the LUF.

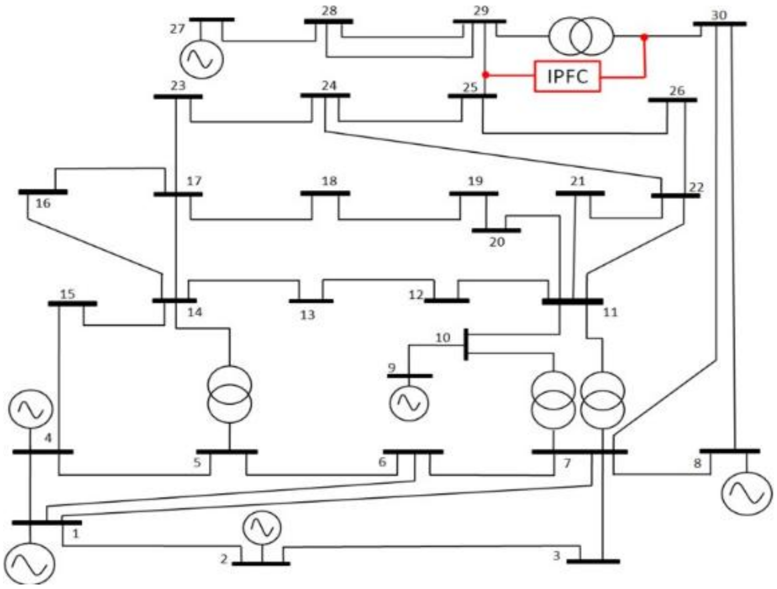


Fig.4 IEEE 30 Bus system with IPFC placed between buses 25-29 and 29-30

V. RESULTS AND DISCUSSIONS

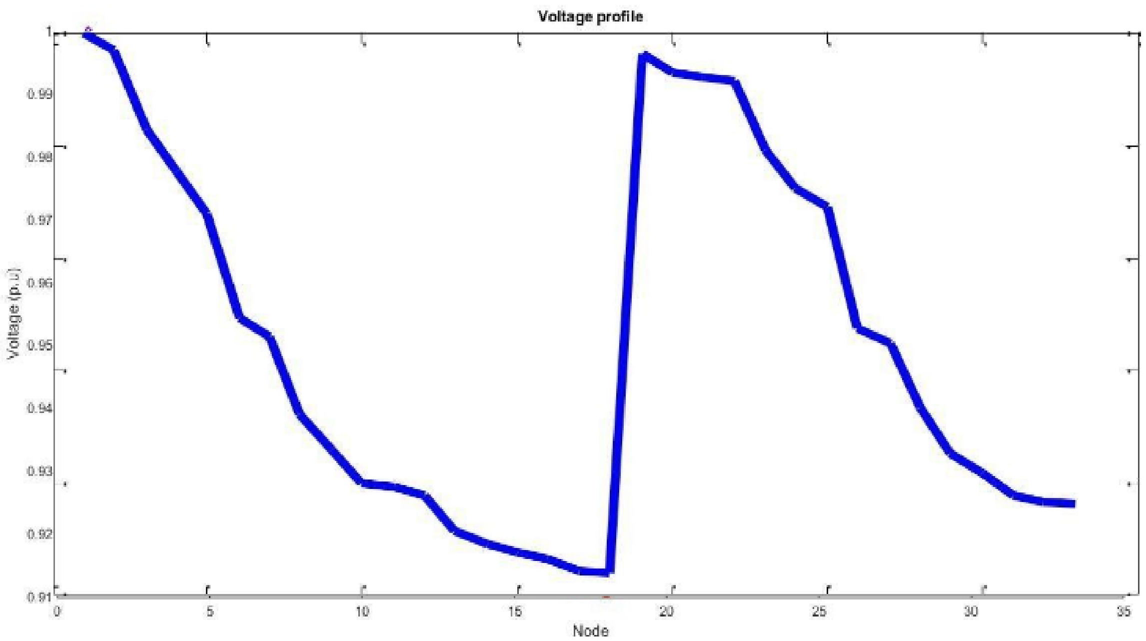


Fig.5. IEEE 30 Bus voltage profile without installation of IPFC

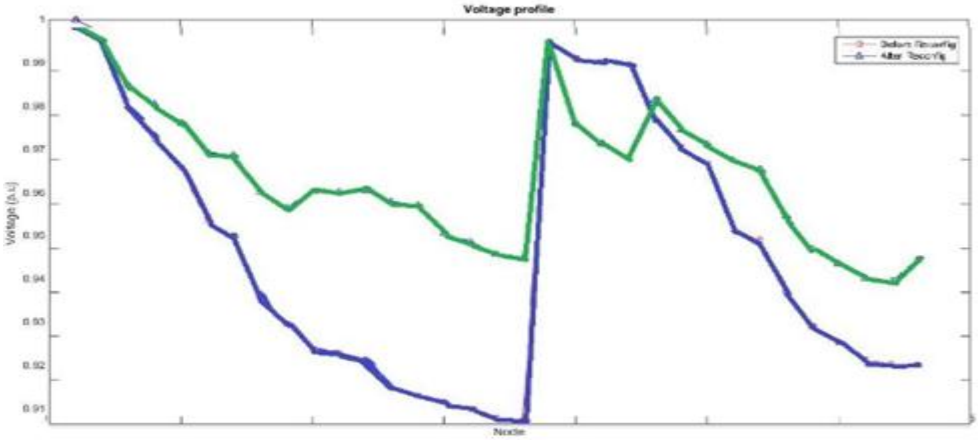


Fig.6. Voltage profile without and with installation of IPFC in IEEE 30 Bus system

Bus No	Without IPFC	With IPFC	Bus No	Without IPFC	With IPFC
1	1.00000	1.0000	18	0.90380	0.9689
2	0.99703	0.9975	19	0.99650	0.9970
3	0.98289	0.9859	20	0.99292	0.9834
4	0.97538	0.9802	21	0.99221	0.9727
5	0.96796	0.9747	22	0.99158	0.9621
6	0.94948	0.9605	23	0.97931	0.9823
7	0.94596	0.9580	24	0.97264	0.9757
8	0.93231	0.9528	25	0.96931	0.9723
9	0.92598	0.9516	26	0.94756	0.9686
10	0.92011	0.9509	27	0.94499	0.9567
11	0.91925	0.9510	28	0.93355	0.9548
12	0.91774	0.9513	29	0.92534	0.9466
13	0.91158	0.9523	30	0.92179	0.9431
14	0.90931	0.9527			
15	0.90790	0.9541			
16	0.90655	0.9563			
17	0.90454	0.9604			

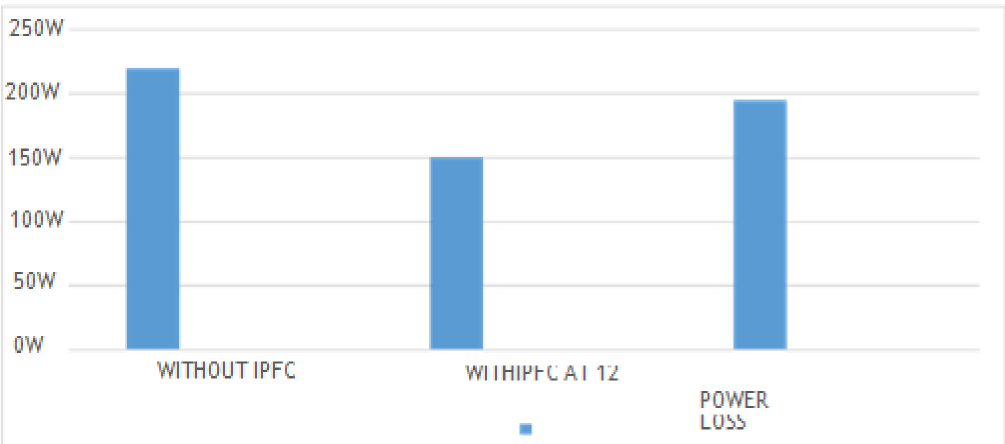


Fig. 7. Power loss without and with installation of IPFC for IEEE 30 Bus system

VI. CONCLUSION

In this paper a new technique is projected for best possible position of IPFC based on cuckoo search algorithm. Subtraction of line utilization factor is projected for best possible sizing of IPFC for overloading organization. The IPFC is located according to the value of SLUF with best possible alteration using CSA. Before inserting IPFC in the best probable site, the fraction of overloading of some line is maximum which leads to trip the line and constant breakdown in the arrangement and close by arrangement as well. Subsequent to utilizing IPFC in the best possible locations, voltage violations are eliminated and overloading is reduced with significant amount. The presentation of CSA is done using IEEE 30-bus test arrangement. The multi objective function is formulated and tuned using CSA and the presentation shows that alteration of IPFC decreases the active power loss and voltage violation in transmission lines. In addition, Optimal tuning much reduces the capability of installed IPFC. It is also noted that the performance of the system improved significantly with IPFC.

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