Real Power Generation optimization and optimal setting of UPFC for Power Loss minimization using Cuckoo Search Algorithm

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Abstract— *This paper presents a nature-inspired algorithm, namely Cuckoo Search Algorithm (CSA) is applied for solving optimal power flow (OPF) problem. The CSA is found to be the most efficient algorithm for solving single objective optimal power flow problems. The CSA is coded in MATLAB and the performance is tested on IEEE 30 bus test system with real power losses minimization as objective function. Unified Power Flow Controller (UPFC) is a multifunctional device in the Flexible Alternating Current Transmission System (FACTS) family. It has capable of controlling the power system parameters like voltage magnitude, line reactance and phase angle either individually or collectively. In this paper UPFC is incorporated in CSA based Optimal Power Flow to optimize the real power generation. UPFC is used to reduce transmission line losses and improve the voltage profile of the system. CSA gives better results as compared to genetic algorithm (GA) in both without and with UPFC conditions.*

Key words: *FACTS device, Cuckoo Search algorithm, Optimal Power Flow, UPFC.*

I. INTRODUCTION

To meet the changing demands of the consumer's, optimization of real power generation is required. But increasing demand and supply in the power systems creates hurdles to the network, and its secure and stable operation has become a challenging task [1]. So for the purpose of supplying the power to consumers effectively power system network reconfiguration is required. In reconfiguration of the power system, Flexible AC transmission system (FACTS) devices play an important role. FACTS devices effectively control the power flow in the power system. Among FACTS devices, Unified Power Flow Controller (UPFC) is a multi functional device which controls the voltage magnitude, phase angle and line reactance individually or collectively [2, 3]. But its performance is depending on the parameters of UPFC so the optimal setting of UPFC parameters is required.

In literature, this problem has been mentioned in various ways. For example, M. Saravanan et al. applied the PSO algorithm for finding size and location of FACTS devices considering the system loadability [4]. In Khai Phuc Nguyen et al. apply the cuckoo search algorithm for optimal placement of static var compensator to improve the performance of the power system. The optimal solution given by Adaptive Differential Evolution algorithm is better than other evolutionary algorithm methods is explained by K.R.Vadivelu et.al [5]. Another research of optimal power flow using cuckoo search algorithm for improvement of voltage stability has been explained by M. A. Elhameed [6]. And the problem of real power generation reallocation is also solved using traditional optimization methods such as interior point, linear programming, nonlinear programming [7] and quadratic programming. Drawbacks in these methods are the difficulty to obtain the global minimum due to many local minimums that exist in these problems. Heuristic optimization tools have been investigated such as evolutionary and genetic algorithm [8-9], particle swarm optimization [10], ant colony [11], Bees algorithm, gravitational search and Tabu search [12] to solve this problem. In this paper Cuckoo search [13] is investigated and applied to IEEE 30 bus system for real power generation optimization and optimal setting of UPFC parameters to minimize the real power losses. Results obtained are compared with genetic algorithm, Cuckoo search gave better results.

The UPFC is advanced FACTS device capable of providing simultaneous control of voltage magnitude, active and reactive power flows [14]. Owing to its fast response and unrivalled functionality, it is able to solve problems related to power flow control. The UPFC, constructed by the combination of the static synchronous compensator (STATCOM) and the static synchronous series compensator (SSSC) that can control power flow in transmission lines, using a series connected power converter. It was introduced by Gyugiy in 1991 [15] and is believed to have the ability in improving power system performance by means of controlling its parameters, like the voltage magnitude and the phase angle. UPFC is connected in both series and shunt (parallel) on a transmission line of a power system. A mathematical model is required for investigating the effects of UPFC on the power system operation that can be used for further analysis.

In this paper, Cuckoo search algorithm has been implemented to solve the single objective function for optimal generation reallocation and optimal sizing of the UPFC devices in electrical power system. It also gives a comparison between Cuckoo search algorithm and Genetic algorithm. IEEE 30 bus system considered for case study to figure out the effect of the proposed method when increasing search space. The real power generation and PV bus voltage magnitude are taken as constraints during the optimization. The obtained results show that UPFC is the most effective compensation devices that can significantly reduce the power losses in the power system

This paper includes six parts. Current part provides a literature review about applications of UPFC in the electric power system and Cuckoo search algorithm. The second part describes about the UPFC device. The next part shows the procedure of Cuckoo search algorithm for implementation of generation reallocation problem with minimization of real power losses. Forth part, describes the problem formulation with objective function. Numerical results are shown in the fifth part and the last part is conclusion..

II. UNIFIED POWER FLOW CONTROLLER

UPFC concept has been proposed by Gyugyi is used for control of power flow in ac transmission system. UPFC provides multifunctional control to solve reactive power compensation and voltage stability improvement problems in the power system. The UPFC is able to control voltage magnitude, line impedance and phase angle singly or jointly to improve the performance of the power system so it signifies the term 'unified' in the UPFC [16].

Static Synchronous Compensator (STATCOM) is a shunt connected voltage source converter type device and a Static Synchronous Series Compensator (SSSC) is a series connected voltage source converter type FACTS device. The combination of above two devices is UPFC in this exchange of real and reactive has been obtained through common DC link. The UPFC consists of two voltage-source converters, one connected in shunt and another one connected in a series. The series converter of the UPFC injects an AC voltage with the controllable magnitude and phase angle in a series with the transmission line via a series connected coupling transformer. The basic function of shunt converter is to supply or absorb the real power demanded by the series converter at the common DC link. It can also generate or absorb controllable reactive power and provide independent shunt reactive compensation for the line. Thereby, the UPFC can fulfil the functions of reactive shunt compensation, a series compensation and phase shifting [17].

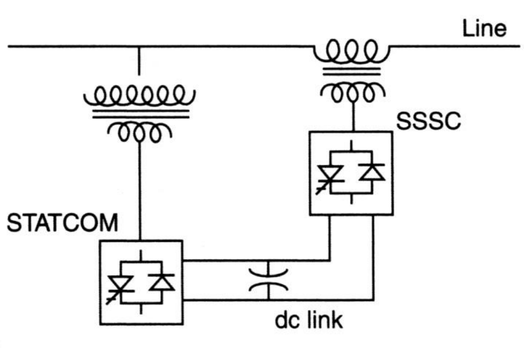

Fig. 1. A simple model of UPFC

UPFC voltage sources are written as:

$$V_{vR}(\cos\delta_{vR} + j\sin\delta_{vR}) \qquad (1)$$

$$V_{cR}(\cos\delta_{cR} + j\sin\delta_{cR}) \qquad (2)$$

Where V_{vR} and δ_{vR} are the controllable voltage magnitude and phase angle of the voltage source representing the shunt converter. Similarly, V_{cR} and δ_{cR} are the controllable voltage magnitude and phase angle of the voltage source representing the series converter. The source impedance is considered to be resistance less.

The active and reactive power equations are

At bus k

$$P_k = [V_k V_m B_{km}\sin(\theta_k - \theta_m)] + [V_k V_{cR} B_{km}\sin(\theta_k - \delta_{cR})] + [V_k V_{vR} B_{vR}\sin(\theta_k - \delta_{vR})] \qquad (3)$$

$$Q_k = -V_k{}^\wedge 2\, B_{kk} - [V_k V_m B_{km}\cos(\theta_k - \theta_m)] - [V_k V_{cR} B_{km}\cos(\theta_k - \delta_{cR})] - [V_k V_{vR} B_{vR}\cos(\theta_k - \delta_{vR})] \qquad (4)$$

At bus m

$$P_m = [V_m V_k B_{mk}\sin(\theta_m - \theta_k)] + [V_m V_{cR} B_{mm}\sin(\theta_m - \delta_{cR})] \qquad (5)$$

$$Q_m = -V_m{}^\wedge 2\, B_{mm} - [V_m V_k B_{mk}\cos(\theta_m - \theta_k)] - [V_m V_{cR} B_{mm}\cos(\theta_m - \delta_{cR})] \qquad (6)$$

At Series converter:

$$P_{cR} = [V_{cR} V_k B_{km}\sin(\delta_{cR} - \theta_k)] + [V_m V_{cR} B_{mm}\sin(\delta_{cR} - \theta_m)] \qquad (7)$$

$$Q_{cR} = -V_{cR}{}^\wedge 2\, B_{mm} - [V_k V_{cR} B_{km}\cos(\theta_k - \delta_{cR})] - [V_m V_{cR} B_{mm}\cos(\theta_m - \delta_{cR})] \qquad (8)$$

At Shunt converter:

$$P_{vR} = [V_{vR} V_k B_{vR}\sin(\delta_{nR} - \theta_k)] \qquad (9)$$

$$Q_{vR} = V_{vR}{}^\wedge 2\, B_{vR} - [V_{vR} V_k B_{vR}\cos(\delta_{vR} - \theta_k)] \qquad (10)$$

The starting values of the UPFC voltage sources are taken to be V_{cr} =0.01 p.u, δ_{cr} =90^0, V_{vr} =1 p.u. and δ_{vr} = 0^0. The source impedances are taken as Z_{cr}=Z_{vr} = 0.1 p.u.

III. CUCKOO SEARCH ALGORITHM

Yang and Deb developed a population-based optimization algorithm, based on the brood parasitism of some cuckoo species in nature and named as a Cuckoo search algorithm [18]. This method simulates the actions of the female Cuckoo bird to lay her egg into the neighbour's nest. This method also considers the probability that the host bird finds out and abandons the Cuckoo egg. A recent study says that Cuckoo search algorithm gives better results as compared to other meta heuristics methods.

The pseudo code of the cuckoo search algorithm is presented in [19-20] based on three main stages as below

• *Initialization*: There is a population of *Np* host nests generated. This stage is corresponding to the phenomenon that cuckoo bird lays its eggs in nests of other species.

• *The first new solution generation*: This stage is to generate the first new solutions via Levy Flights corresponding to the case that host birds do not discover alien eggs in their nest and Cuckoo eggs will be hatched and carried over to the next generation.

•*The second new solution generation*: This stage aims to generate the second new solutions corresponding to the case that the host birds discover Cuckoo eggs as alien ones in their nest and host bird will throw Cuckoo eggs away the nest or forsake both Cuckoo eggs and their nest.

A random set of solution is generated using Levy flight algorithm:

$$X_i^{t+1} = X_i^t + \alpha \bigoplus Levy(y)$$

Above equation is the stochastic equation of a random walk whose next step depends on current location (the first term) and the transition probability (the second term). α is the step size, the product means entry wise multiplications. Levny flight provides a random walk whose random step length is drawn from Levy distribution:

$$Levy \neq t^{-\lambda}, (1 < \lambda < 3)$$

Steps form a random walk process with a power-law step length distribution with a heavy tail. Objective function with this new set is also evaluated. If new objective function is better than old one, a portion Pa of new set is replaces an equivalent random set of the initial solution. The process is repeated until the maximum number of epochs is reached. Initial set of nests (n nests) may vary from 15 to 40 and Pa of 0.25 are suitable values for most optimization problems [21].

Overall Procedure

The overall procedure of the CSA for solving the optimization problem is described in detail as follows.

Step 1: Read the power system bus data and line data for power flow calculations.

Step 2: Select the real power generation of all the PV buses and UPFC parameters as a control variables also select the number of nests *Np*, the maximum number of iterations *Itermax* and probability *pa*. Initialize a population of host nests.

Step 3: Get a cuckoo randomly/ generate solution by Levy flights algorithm and evaluate its objective function.

Step 4: Perform bound by best solution mechanism as described in algorithm to repair solutions violating upper or lower limitation.

Step 5: Generate the new solutions thank to the action of alien eggs to be abandoned and replace the old solution by the new one.

Step 6: Get the best nest *Gbest* for the current iteration.

Step 7: If the best nest *Gbest* at the current iteration is not better than that of the previous iteration, obtain the new value of the one rank ratio. Otherwise, retain the old value.

Step 8: If *Iter* < *Itermax*, *Iter* = *Iter* + 1 and return to Step 3. Otherwise, stop the procedure.

Step 9: If termination criterion is satisfied, then find the best solution in the search space.

IV. PROBLEM FORMULATION

Objective function

For a given system load, find the best configuration of UPFC device and real power generation of the generating stations based on the minimizing the real power losses.

$$Min\ F = Min(F_{PLoss}) \quad (11)$$

This objective consists of minimizing the real power losses in the transmission lines. It can be expressed as

$$F_{PLoss} = \min(P_{Loss}) = \min\left(\sum_{k=1}^{ntl} real(S_{ij}^k + S_{ji}^k)\right) \quad (14)$$

Where ntl=no. Of transmission lines

S_{ij} is the total complex power flow from bus i to bus j in line k.

Subject to power balance constraints

$$\sum_{i=1}^{N} P_{Gi} = \sum_{i=1}^{N} P_{Di} + P_L \quad (15)$$

Where i=1,2,3,.......,N and N = no. of. Buses

Voltage constraint:

$$V_{Gi}^{min} \leq V_{Gi} \leq V_{Gi}^{max} \quad (16)$$

Where Gi=1, 2, 3,.......,ng and ng = no. of. PV buses

Real power generation limit:

$$P_{Gi}^{min} \leq P_{Gi} \leq P_{Gi}^{max} \quad (17)$$

Where Gi=1, 2, 3,......,ng and ng= no. of. PV buses

UPFC device limits:

$$V_{vr}^{min} \leq V_{vr} \leq V_{vr}^{max} \quad (18)$$

V_{vr} is the shunt converter voltage magnitude (p.u)

$$V_{cr}^{min} \leq V_{cr} \leq V_{cr}^{max} \quad (19)$$

V_{cr} is the series converter voltage magnitude (p.u)

where P_L is the active power loss in the system, P_{Gi} is the active power generation at bus *i*, P_{Di} is the power demand at bus *i*, *N* and *ng* are the number of buses and no of generators in the system respectively. The limits of Voltage Magnitudes of the PV buses are taken between 0.9p.u and 1.1pu.

V. RESULTS AND DISCUSSIONS

In order to demonstrate the performance of the Cuckoo Search Algorithm in Optimal Power Flow with UPFC, IEEE30 bus system is considered. An OPF program using Cuckoo Search algorithm for minimization of real power losses is written using MATLAB without the UPFC, which was further extended with the UPFC. A MATLAB program is coded for the test system and the results are presented and analysed. The input parameters of Cuckoo Search Algorithm and Genetic algorithm for the test systems are given in the Table 1 and Table2 respectively.

First run the Cuckoo Search Algorithm (CSA) based optimal power flow without incorporating the UPFC. Voltage magnitudes of CSA without UPFC are given in Fig.4. From this figure it is observed that voltage magnitude at bus 30 is less compared to all other buses. So to improve the voltage profile of the system UPFC shunt converter is placed at bus number 30. And series converter is placed in line which is connected to bus 30 so the UPFC is placed between bus no 29 and bus no 30.

Table 1: Input parameters of Cuckoo Search Algorithm

S.No	Parameters	Quantity
1	Number of nests	20
2	Number of iterations	100
3	Discovery rate of alien eggs/solutions	0.25

Table 2: Input parameters of Genetic Algorithm

S.No	Parameters	Quantity
1	Population size	20
2	Maximum number of Generations	100
3	Crossover Fraction	0.8
4	Migration Fraction	0.2
5	Migration Interval	20

IEEE 30 bus system:

In IEEE 30 bus system bus no 1 is considered as a slack bus and bus numbers 2, 5, 8, 11 and 13 are considered as a PV buses all other buses are considered as load buses. This system has 41 interconnected lines. A MATLAB program is coded for the test system and the results are presented and analysed.

Table 3: Comparison of real and reactive power losses for 30 bus system without UPFC and with UPFC placed between bus no 29 and bus no 30

	Power Flow Solution	Total real power generation (MW)	Total Real power loss(MW)	Total Reactive Power Losses (MVAR)
NR Method	Without UPFC	290.73	7.33	11.97
	With UPFC	290.02	6.62	8.57
GA-OPF	Without UPFC	289.5	6.0999	7.45
	With UPFC	288.2878	4.8879	5.92
CSA-OPF	Without UPFC	287.8788	4.4789	5.01
	With UPFC	287.0044	3.6043	2.63

Table 4: UPFC parameters using Cuckoo Search algorithm

UPFC placed between bus number 29 and 30	
Series converter voltage in p.u	0.0400
Series converter angle	-87.1236
Shunt converter voltage in p.u	1.0066
Shunt converter angle	-10.5476

Table 5: Comparison of the Real power generation of PV busses in various methods

PV bus NO	Generation limits		NR Method With UPFC	GA-OPF With UPFC	CSA-OPF Without UPFC	CSA-OPF with UPFC
	Min	Max				
1	50	200	150.02	101.1190	53.3119	53.0759
2	20	80	40.00	72.6712	79.9400	79.8137
5	15	50	40.00	49.6716	49.8436	49.5588
8	10	35	20.00	21.8651	35.00	34.9848
11	10	30	20.00	15.1568	30.00	29.8452
13	12	40	20.00	27.8041	39.7833	39.7260

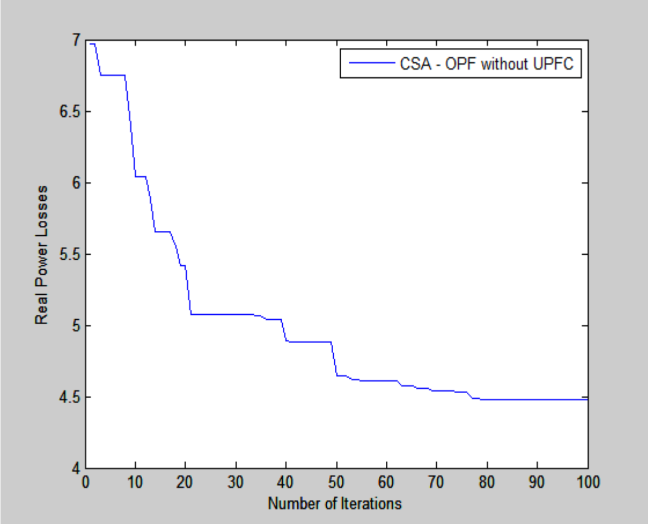

Fig. 2. Convergence characteristics of real power losses with CSA-OPF without UPFC

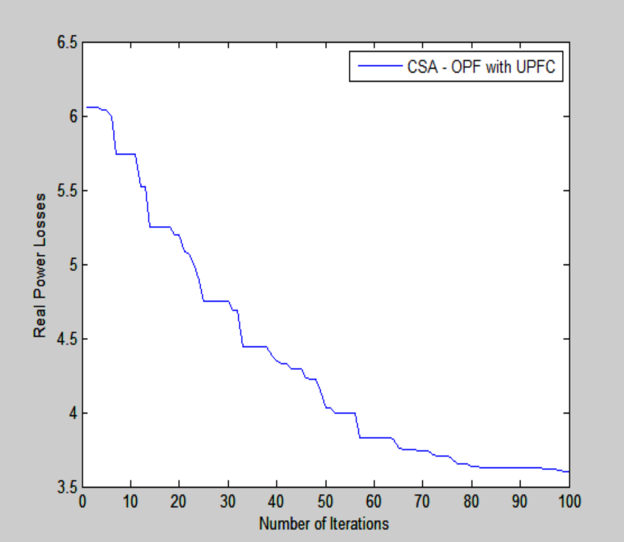

Fig. 3. Convergence characteristics of real power losses with CSA-OPF with UPFC

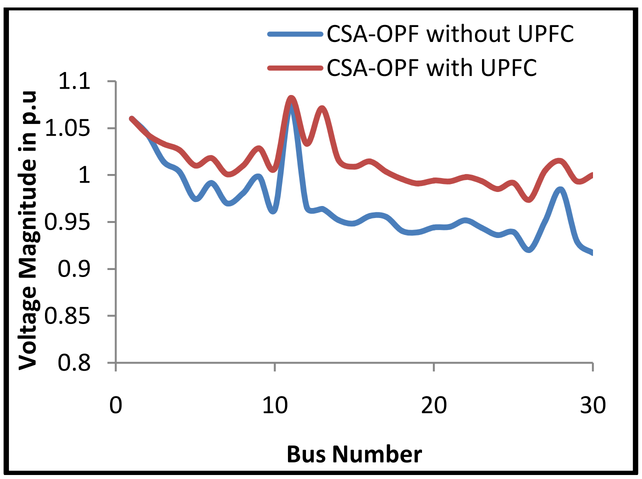

Fig 4.Comparision of the Voltage Magnitudes with and without UPFC

The active power generation and power loss for the IEEE 30 bus system without and with UPFC are shown in Table3. From Table 3, it can be seen that the total active power generation required is reduced to 287.0044 MW from 287.8788 MW and power loss are reduced to 3.6043 MW from 4.4789 MW due to UPFC in Cuckoo search Algorithm based OPF. Table 4 indicates the parameters of the UPFC device. Table 5 represents the active power generation of PV buses for different conditions those are NR method with UPFC, GA method with UPFC and Cuckoo search algorithm based Optimal Power Flow without and with UPFC. By using Cuckoo search Algorithm Generation reallocation has been done properly resulting in less power loss. Figure 4 indicates the voltage profile of 30 bus system using Cuckoo search Algorithm based Optimal Power Flow without and with UPFC. It indicates that by incorporating the UPFC in line connected between bus no 29 and bus no 30 in Cuckoo search algorithm based OPF voltage profile also improved.

V. CONCLUSION

In this paper, cuckoo search algorithm has been applied to find the optimal values of the generating stations and optimal setting of the UPFC parameters based on minimization of the real power losses. The results obtained with cuckoo search algorithm are compared with genetic algorithm. The Cuckoo search algorithm is totally dominant and successful for determining optimal parameter setting of the UPFC device. Optimizing size of UPFC devices along with optimization of real power generation is a complex problem. It combines continuous and discrete numbers with many equal and unequal constraints. However, according to case studies, the Cuckoo search always gives the better solution with the higher performance. Comparing with genetic algorithm based optimization, Cuckoo search algorithm may converge slower at the beginning, but it always gives better solution at the end of search process. The results obtained for the IEEE 30 bus system, using the implemented method without and with UPFC are compared and observations reveal that the real power losses are reduced with UPFC. The obtained results are supportive, and show that UPFC is the most effective devices that can significantly increase the performance of the power system and also improve the voltage profile of the power system.

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