Voltage stability index based optimal placement of Static VAR Compensator and sizing using Cuckoo Search Algorithm

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Abstract. This paper furnish the new Metaheuristic algorithm called Cuckoo Search Algorithm (CSA) for solving optimal power flow (OPF) problem with minimization of real power generation cost. The CSA is found to be the most efficient algorithm for solving single objective optimal power flow problems. The CSA performance is tested on IEEE 57 bus test system with real power generation cost minimization as objective function. Static VAR Compensator (SVC) is one of the best shunt connected device in the Flexible Alternating Current Transmission System (FACTS) family. It has capable of controlling the voltage magnitudes of buses by injecting the reactive power to system. In this paper SVC is integrated in CSA based Optimal Power Flow to optimize the real power generation cost. SVC is used to improve the voltage profile of the system. CSA gives better results as compared to genetic algorithm (GA) in both without and with SVC conditions.
Key words. Cuckoo Search algorithm, Optimal Power Flow, Voltage Stability Index, SVC.

INTRODUCTION

Load requirement of the consumer’s is keep on changing so meet this changing load, optimization of real power generation is required. The increasing load demand in the power systems creates difficulties to the power system, 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 [2]. By incorporating FACTS devices in power system voltage profile can be improved and losses can be reduced. Among FACTS devices SVC can effectively increase the voltage profile of the system though, as enormous capital investment is required for the installation of SVC device, a thorough investigation is required at the planning stage itself to place this device optimally in the power system.

In this paper, one of the Voltage stability index called L index has been proposed to locate the SVC device optimally in the power system and the desired size of SVC device is obtained by minimizing the objective function i.e reduction in real power generation cost has been carried out using newly developed cuckoo’s search algorithm. A shunt connected SVC is a shunt type FACTS device. Its output is adjusted by exchanging capacitive or inductive reactive power to the system to maintain the specified voltage at the bus [3].

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]. The optimal placement of FACTS devices using genetic algorithm method is explained by Gerbex 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 sizing of real power generation is also solved using conventional optimization methods [7] such as interior point method, non linear programming method, linear programming method and differential evolution programming method. In these methods it is difficult to obtain the global minimum sometimes due to many local minimums. Heuristic optimization tools have been developed to solve the above problem those are genetic algorithm [8-9], particle swarm optimization, ant colony [10], Bees algorithm, gravitational search and cuckoo search algorithm [11].

In this paper Cuckoo search algorithm method is used and applied to IEEE 57 bus system for optimal sizing of real, reactive power generation and optimal sizing of SVC to minimize the real power generation cost. Results obtained are compared with genetic algorithm, Cuckoo search gave better results.

STATIC VAR COMPENSATOR

SVC is one of the popular shunt connected FACTS device to improve the voltage profile of the system. SVC is has two models those are susceptance model and firing angle model [12]. In this paper shunt susceptance model has been used. The SVC value is tuned in order to obtain the voltage magnitude at the bus is 1.0pu. The SVC device may be inject or absorb the reactive power depend on the bus requirement. The shunt susceptance model is shown in Figure .1[13-14].

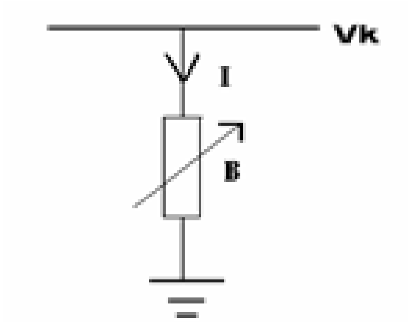

FIGURE 1. Susceptance model of SVC

SVC draws the current

$$I = jBV_k \tag{1}$$

Absorbed or injected reactive power by the SVC at bus k is

$$Q_{svc} = V_k^2 B \tag{2}$$

The susceptance of the SVC is given in equation 3. The total susceptance Bsvc is taken as the state variable. SVC value is updated based on optimization rules.

$$\begin{bmatrix} \Delta P_k \\ \Delta Q_k \end{bmatrix}^i = \begin{bmatrix} 0 & 0 \\ 0 & Q_k \end{bmatrix}^i \begin{bmatrix} \Delta\theta_k \\ \Delta B_{svc} / B_{svc} \end{bmatrix}^i \tag{3}$$

The initial value of the SVC susceptance is taken as B=0.04p.u, Bmin= -1.0p.u, Bmax=1.0p.u

Optimal placement of the SVC using L Index

In this paper L index is used to identify the weak bus that is the best location for placement of SVC to improve the voltage profile of the power system. The L index is computed using equation 4.

$$L_j = \left| 1 - \sum_{i=1}^{g} F_{ji} \frac{V_i}{V_j} \right| \tag{4}$$

Where g is the no.of generator buses, j is the load bus number. The L index is calculated for all the load buses. Lj value is near to the one indicates that the system is moving towards the voltage collapse state [15-16]. To avoid this problem SVC is placed at that bus to improve the stability of the system.

CUCKOO SEARCH ALGORITHM

Yang and Deb introduced a nature inspired optimization algorithm, based on the brood parasitism of some cuckoo group in nature and named as a Cuckoo search algorithm [17]. This method simulates the actions of the female Cuckoo bird to lay her egg into the neighbour's nest. This method also considers the possibility 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 metaheuristic methods. The pseudo code of the cuckoo search algorithm is presented in [18] based on Initialization. In this 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. In the new solution generation stage a new solutions is generated 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 next 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 arbitrary set of solution is generated using Levy flight algorithm:

$$X_i^{t+1} = X_i^t + \alpha * \text{Levy}(y) \quad (5)$$

Equation 5 is the stochastic equation of a random walk its next step depends on current location and the transition probability. Where α is the step size. Levny flight provides a random walk its random step length is pinched from Levy distribution:

$$\text{Levy} \neq t^{-\lambda}, (1 < \lambda < 3) \quad (6)$$

Objective function with this new set is also evaluated. If new value is better than old one, a new set is replaces a set of the initial solution. The process is repeated until the maximum number of iterations is reached. Initial set of nests may vary from 15 to 40 in this paper number of nests consider as 20 and Discovery rate of alien eggs is consider as 0.25.

Overall Procedure

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

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

Step 2: Select the real and reactive power generation of all the generator buses and SVC size as a control variables also select the number of nests Np, the maximum number of iterations $Iter_{max}$ and Discovery rate of alien eggs. Initialize a population of host nests.

Step 3: Get a cuckoo to 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 process.

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

PROBLEM FORMULATION

The objective of this paper is to determine the optimal size of real, reactive power generators and optimal sizing of the SVC devices in the IEEE 57 bus system using cuckoo search optimization method to consider the sum of the real power generation cost as a objective function, static load flow equations as a equality constraints and the limits of the real, reactive power generators as a inequality constraints.The objective function is given as

$$F = \min\left(\sum_{i=1}^{ng} a_i P_{Gi}^2 + b_i P_{Gi} + c_i\right) \quad (7)$$

a, b, c are the cost coefficients of a generator bus

Equality constraints:

$$\sum_{i=1}^{N} P_{Gi} = \sum_{i=1}^{N} P_{Di} + P_L \quad (8)$$

$$\sum_{i=1}^{N} Q_{Gi} = \sum_{i=1}^{N} Q_{Di} + Q_L \quad (9)$$

Inequality constraints:

$$V_{Gi}^{min} \le V_{Gi} \le V_{Gi}^{max} \quad (10)$$

$$P_{Gi}^{min} \le P_{Gi} \le P_{Gi}^{max} \quad (11)$$

$$Q_{Gi}^{min} \le Q_{Gi} \le Q_{Gi}^{max} \quad (12)$$

$$B_{svc}^{min} \le B_{svc} \le B_{svc}^{max} \quad (13)$$

PL is the active power loss in the system, PGi is the active power generation at bus i, PDi 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 generator buses are taken between 0.9p.u and 1.1pu.

RESULTS AND DISCUSSIONS

In order to illustrate the significance of the Cuckoo Search Algorithm in Optimal Power Flow with SVC, IEEE57 bus system is used. An OPF program using Cuckoo Search algorithm for minimization of real power generation cost is developed using MATLAB for both without and with SVC. The input parameters of Cuckoo Search Algorithm and Genetic algorithm for the test systems are given in the Table 1 and Table2 respectively. In IEEE 57 bus system bus no 1 is considered as a slack bus and bus numbers 2, 3, 6, 8, 9 and 12 are considered as a generator buses all other buses are considered as load buses. This system has 80 interconnected lines. Generator cost coefficients of IEEE57 bus system are given in Table 3.

TABLE 1. Cuckoo Search Algorithm Input parameters

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. Genetic Algorithm Input parameters

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

TABLE 3. IEEE 57 Bus System Generator Characteristics

Generator bus no	a ($/MW^2/hr)	b ($/MW/hr)	c ($/hr)	P_G^{min} (MW)	P_G^{max} (MW)
1	0.0775	20	0	0	575
2	0.01	40	0	0	100
3	0.25	20	0	0	140
6	0.1	40	0	0	100
8	0.02222	20	0	0	550
9	0.01	40	0	0	200
12	0.32258	20	0	0	410

TABLE 4. L index values in IEEE 57 Bus System

Rank	Bus Number	L Index Value	Rank	Bus Number	L Index Value
1	31	0.3811	26	20	0.1513
2	33	0.3589	27	44	0.1446
3	32	0.3537	28	43	0.1413
4	57	0.3391	29	46	0.1324
5	42	0.3377	30	19	0.1173
6	56	0.3358	31	14	0.1087
7	30	0.3173	32	53	0.1078
8	41	0.2761	33	51	0.1029
9	25	0.2744	34	10	0.095
10	34	0.2738	35	54	0.0905
11	35	0.2607	36	7	0.0878
12	40	0.2478	37	27	0.0872
13	36	0.2431	38	13	0.0857
14	39	0.2318	39	52	0.0816
15	37	0.2275	40	45	0.0628
16	23	0.182	41	55	0.0625
17	22	0.1808	42	11	0.0619
18	38	0.1797	43	16	0.0557
19	24	0.1769	44	5	0.0521
20	21	0.1757	45	28	0.0492
21	26	0.172	46	18	0.0416
22	48	0.1674	47	17	0.039
23	47	0.1641	48	15	0.026
24	50	0.1621	49	29	0.0213
25	49	0.1536	50	4	0.0039

TABLE 5. Real and reactive power generation of Generator busses in various methods

	CSA-OPF Without SVC	**GA-OPF With SVC**	**CSA-OPF With SVC**
PG1(MW)	225.8888	241.8295	206.0142
PG2(MW)	81.7472	100.0000	100.00
PG3(MW)	68.9264	69.8740	71.2332
PG6(MW)	56.9438	100.0000	55.70
PG8(MW)	550.00	550.0000	549.7924
PG9(MW)	200.00	110.6312	200.00
PG12(MW)	60.9355	71.9212	61.0287
QG1(MVAR)	147.9437	192.9261	200.8141
QG2(MVAR)	-17.00	-91.7121	-127.2971
QG3(MVAR)	-10.000	-31.2231	-20.2264
QG6(MVAR)	13.3742	31.8941	14.1923
QG8(MVAR)	52.2641	-15.8521	-5.8735
QG9(MVAR)	9.00	55.1237	50.5283
QG12(MVAR)	155.00	188.1347	206.5204
Total real power generation (MW)	1244.442	1244.255	1243.769
Total reactive power generation (MVAR)	350.582	329.2913	318.6582
Total real power generation cost ($/hr)	45615.2	47643.65	45375.1
Active power Loss (MW)	48.6418	48.4559	47.9684
Size of SVC in p.u	---	0.2686	0.2434

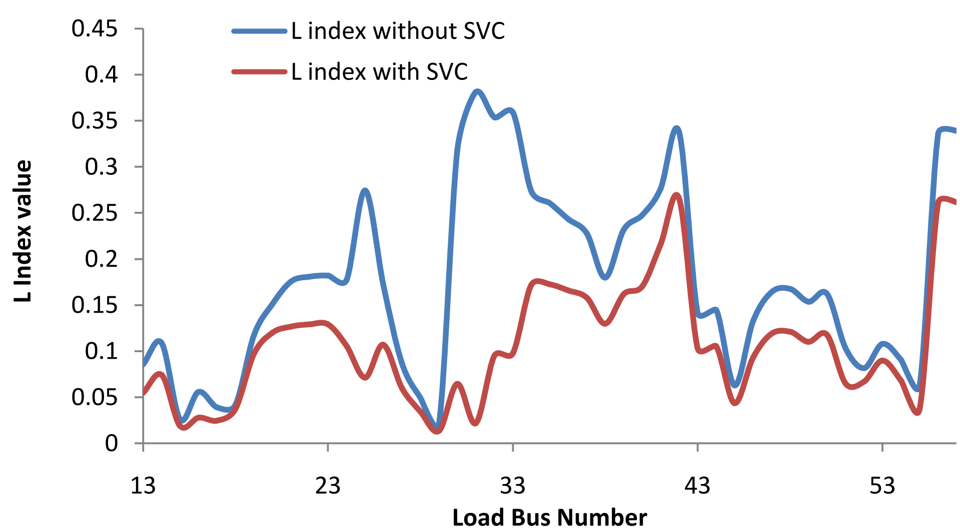

FIGURE 2. Comparison of L index with and without SVC using Cuckoo Search Algorithm

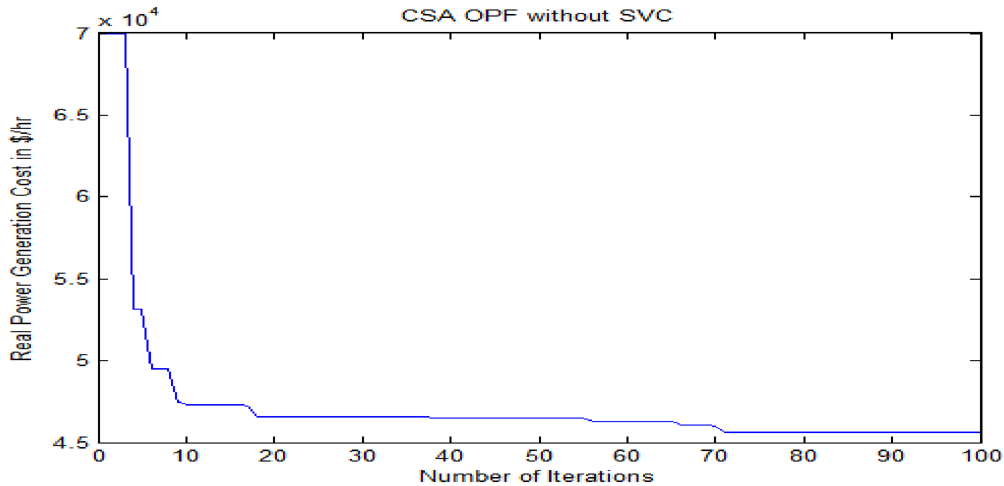

FIGURE 3. Convergence characteristics of real power generation cost with CSA-OPF without SVC

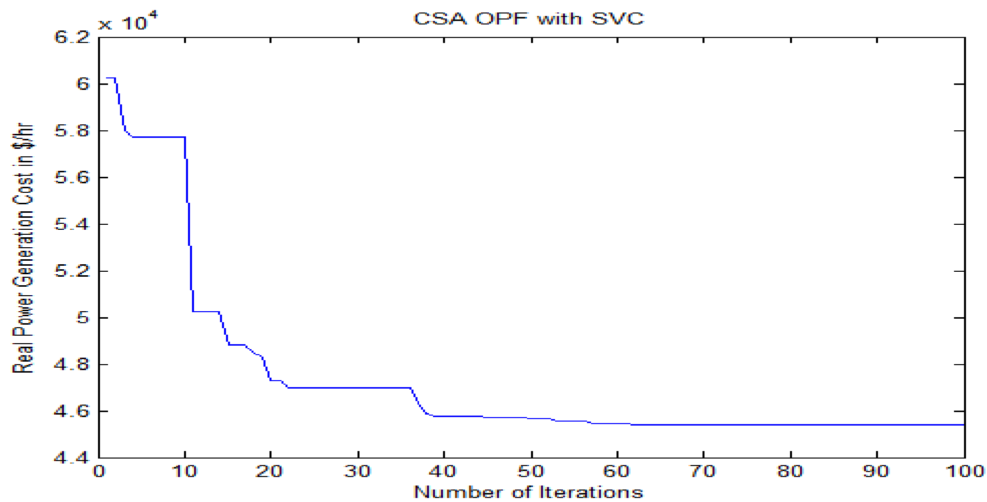

FIGURE 4. Convergence characteristics of real power generation cost with CSA-OPF with SVC

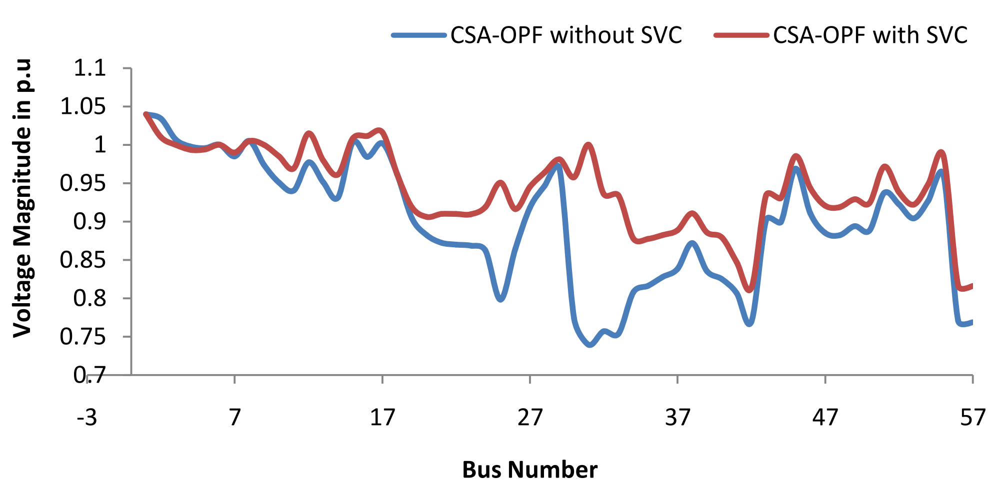

FIGURE 5. Comparison of the Voltage Magnitudes with and without SVC

L index values for IEEE 57 bus system given in Table4 from this table it is observed that L index value is high for bus number 31 which indicates that this bus is the weakest bus. So bus number 31 is the best location for placement of SVC. In this analysis SVC is placed at bus number 31 in IEEE 57 bus system and the size of the SVC is 0.2434p.u in cuckoo search algorithm based optimal power flow incorporating SVC. The active, reactive power generation, power loss and real power generation cost for the IEEE 57 bus system without and with SVC are given in Table5. From Table 5, it can be seen that the total active power generation required is reduced to 1243.769 MW from 1244.442 MW due to SVC in Cuckoo search Algorithm based OPF. This Table also indicates the size of the SVC device. Table 5 also represents the active power generation of generator buses for different conditions those are GA method with SVC and Cuckoo search algorithm based Optimal Power Flow without and with SVC. From this table it is also observed that objective function value that is real power generation cost is 45375.1 $/hr in Cuckoo search Algorithm based OPF with SVC which is less compared to 47643.65 $/hr in GA OPF with SVC. This indicates that sizing of real and reactive power generation of the generators has been done properly. Figure 2 indicates the L index values in CSA OPF without and with SVC from this it has been observed that after placing SVC in bus number 31, voltage stability of the system has been improved. Figure 3 and Figure 4 represents the convergence characteristics of the real power generation cost in CSA OPF without SVC and with SVC respectively. From these two figures it is observed that objective function converges quickly after incorporating SVC in CSA based OPF. Figure 5 indicates the voltage profile of 57 bus system using Cuckoo search Algorithm based Optimal Power Flow without and with SVC. It indicates that voltage profile has been improved by incorporating the SVC in bus 31 in Cuckoo search algorithm based OPF.

CONCLUSION

In this paper, generation reallocation is carried out using Genetic and Cuckoo search algorithms. A cuckoo search algorithm based solution was seen to give better results than Genetic algorithm. For further improvement in the system's performance, SVC is incorporated and analyzed. Voltage stability index called L-index technique is used to identify the optimal location for the placement of the SVC. SVC sizing and generation reallocation are done using Genetic and Cuckoo search Algorithms. Optimal Power Flow solutions are obtained by considering real power generation cost as a single objective function. From the obtained results, the Cuckoo search algorithm gave better results as compared to the genetic algorithm.

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