Optimum Cost of Generation and Active Power Loss Minimization using GA and PSO Techniques in a Power System Network

A. R. Bhowmik [1] A. K. Chakraborty [2] P. N. Das[3]

Abstract–This paper utilizes the application of Particle Swarm Optimization (PSO) and Genetic Algorithm (GA) techniques to find the most appropriate locations of Unified Power Flow Controller (UPFC) with optimum cost of generation for loadability limit and minimum active power loss, while satisfying the power system constraints. Two objective functions are taken as the indexes of the system performance: (i) identification of suitable buses using line loss sensitivity index and optimum cost of generation and (ii) minimization of active power losses by employing PSO and GA techniques separately. The presented methodology has been applied and tested under simulated condition on modified IEEE 14-bus system. The implementations of PSO show that it converges to better solution much faster than GA. The results obtained are quite encouraging and will be useful in electrical power system network.

Keywords–Flexible AC Transmission Systems (FACTS), loss sensitivity index, optimal power flow, GA, PSO, UPFC

I. INTRODUCTION

Due to the increase in power demand, modern power system networks are being operated under extremely stressed conditions. Hence, there is an interest in better utilization of available power transmission capacities by installing new devices such as Flexible AC transmission Systems (FACTS). Recently interests in FACTS devices have risen for higher controllability of the power system network worldwide [1]. Among all FACTS devices, UPFC offers significant multifunctional flexibility required to solve various problems in power system. It can control all the parameters affecting power flow in the transmission line namely voltage magnitude, phase angle and impedance. On the other hand, it can also in parallel control both the real and reactive power flow in the line [2]. However, to ensure the full potential of utilization for maintaining the stability and reliability of existing system, optimal placement of the UPFC is a major issue.

Many researchers have proposed different approaches of installing UPFC in the power system network [2][3][4]. New algorithms have been planned for the suitable placement of UPFC to increase various power system parameters. Wong et al. [5] presented an evolutionary programming load flow algorithm to solve the load flow problem for systems containing UPFC.

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A sensitivity index based approach was proposed for the suitable placement of Thyristor Controlled Series Capacitor (TCSC) and UPFC to enhance the power system Wartana et al. [6] proposed the application of a Non-dominated Sorting Genetic Algorithm II (NSGA-II) for the optimal placement of UPFC to improve the operation of the power system loadability [7]. Saravanan et al. [8] used PSO technique for finding the optimal allocation of TCSC, SVC and UPFC to attain utmost system loadability with least cost of installation. Singh et al. [9] suggested sensitivity based approach for the suitable locations of UPFC to increase power system loadability. Majumder et al. [10] proposed minimization of power losses using FACTS devices with Modified Simulated Annealing and PSO techniques. M. Kowsalya et al. [11] proposed particle swarm optimization to find the global optimum solution for the loss minimization by optimally placed UPFC in the power system network. Esmin et al. [12] first investigated the critical area in a power system with the tangent vector and secondly, used PSO to calculate the amount of shunt reactive power compensation.

In this paper the appropriate location of UPFC was identified using line loss sensitivity index. GA and PSO techniques separately applied to achieve minimum active power loss while satisfying the power system constraints. The methodology has been applied and tested under simulated condition on modified IEEE 14-bus system.

II. MODELING OF UPFC FOR OPTIMAL PLACEMENT

The UPFC is used for the static and dynamic compensation of ac transmission systems. It consists of two voltage source converters (VSCs) as shown in fig. 1. These back-to-back converters, labeled ‘converter 1’ and ‘converter 2’ in the fig. 1, share a common dc link including a dc storage capacitor. The real power exchanged at the ac terminal is transformed into dc power which appears at the dc link [2].

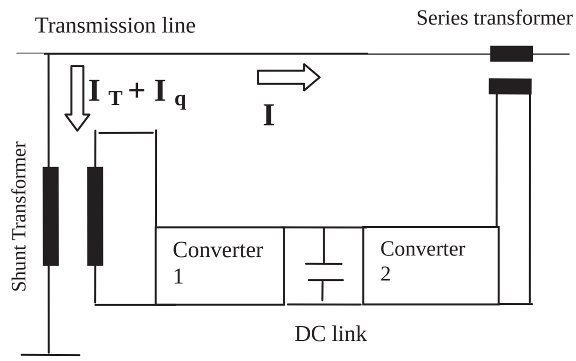

Fig. 1: Basic circuit arrangement of UPFC

The basic responsibility of converter 1 is to provide or absorb the real power demanded by converter 2 at the common dc link. This dc link power demand of converter 2 is transformed back to ac by converter 1 and coupled to the transmission line through a shunt transformer. The basic scheme of the UPFC is shown in Fig. 2.

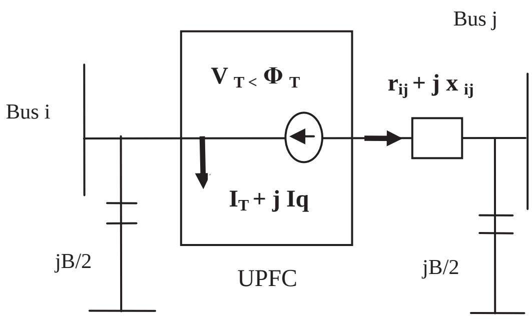

Fig. 2: Equivalent Circuit of UPFC

The real and reactive power with the system loading (λ) is determined by the following equation [9]

$$P_i = P_{Gi} - P_{Di}^0(1+\lambda) = \sum_{j\in N_b} P_{ij} \quad (1)$$

$$Q_i = Q_{Gi} - Q_{Di}^0(1+\lambda) = \sum_{j\in N_b} Q_{ij} \quad (2)$$

where P_{Di}^0 and Q_{Di}^0 are the real and reactive power demands. P_{Gi} and Q_{Gi} are the real and reactive power generations at bus-*I*, respectively. The real power loss sensitivity index is determined using (1)

$$C_1^K = -2V_i g_{ij} \cos(\partial_i) + V_j[g_{ij} \cos(\partial_j) - b_{ij} \sin(\partial_j)] / P_{Di}^0 \quad (3)$$

$$C_2^K = -2V_i g_{ij} \sin(\partial_i) + V_j[-g_{ij} \sin(\partial_j) + b_{ij} \cos(\partial_j)] / P_{Di}^0 \quad (4)$$

The reactive power loss sensitivity index is set according to (2)

$$C_3^k = (V_i(-g_{ij} \sin(\partial_i) + b_{ij} \cos(\partial_i))) / Q_{Di}^0 \quad (5)$$

$$C_4^k = (V_i(g_{ij} \cos(\partial_i) + b_{ij} \sin(\partial_i))) / Q_{Di}^0 \quad (6)$$

where C_1^k, C_2^k are the real power loading sensitivity with respect to the series injected voltage magnitude (V_T) and the series injected phase angle (Φ_T) of the UPFC and C_3^k, C_4^k are the reactive power loading sensitivity with respect to the series injected voltage magnitude (V_T) and the series injected phase angle (Φ_T) of the UPFC respectively ,where $g_{ij} + jb_{ij} = \frac{1}{r_{ij} + jx_{ij}}$ and I_q is the reactive current flowing in the shunt transformer to improve the voltage of the shunt connected bus of UPFC.

III. Genetic Algorithm

Genetic Algorithms (GA) have recently been applied in the optimization of power systems as these are very effective and flexible optimizing techniques. These are the search algorithms, invented by Holland in the early 1970s [13]. In this paper, a binary coded GA where every control variable is prearranged into a succession of binary bits is used. In GA, Each generation belongs to a population of strings and the next generation is formed by the simulation of reproduction, gene crossover and mutation. It also effectively uses the information of new population to direct the next search [14]. In GA first a random initial population is generated, evaluated and starts creating new population by using reproduction, gene crossover and mutation as follow [15]:

1. Start
2. Generate (*Old population*)
3. Repeat Until limit

    Evaluate (*Old population*)
    New population = select (*Old population*)
    Cross over (*new population*)
    Mutation (*new population*)
    Old population = *new population*
4. End.

IV. Particle Swarm Optimization

PSO is developed through simulation of bird flocking in two dimensional spaces. It is a popular non conventional optimization technique with high global searching capability. The main reason behind its wide spread use in power system is its simplicity and generating high quality solutions within very short duration. PSO has the same flexibility as compared to the other heuristic algorithms for controlling the stability between the global and local investigation of the search space [16]. PSO finds the best possible solution with a population of particles where each particle represents a candidate solution to the problem [10]. The change in position depends on previous, best individual, best global and a random velocity position. The terms individual best, global best and random velocity are responsible for changes in particle position during iterations are associated with values called inertial weights. In general, maximum number of iterations for termination of the search process and inertia weight factor w is set according to the following equation:

$$w = w_{maz} - \frac{w_{\max} - w_{\min}}{iter_{\max}} \cdot iter \quad (7)$$

where w is the inertia weight, $iter_{\max}$ is the maximum iteration number, "$iter$" is the current iteration number, $w_{\max}$ is the initial value of inertia weight equal to 0.9 and $w_{\min}$ is the final value of inertia weight equal to 0.4.The pseudo code of the procedure is as follows:

Initialize particle
End
Do
Calculate fitness value
If the fitness value is better than the best fitness value (P_{best}) set current value as the new P_{best}
End
Particle with the best fitness value of all the particles= g_{best}
Calculate particle velocity as the following equation
*V ( ) = V ( ) + c1 * rand ( ) *[(P_{best} () – Present ( )] + c2 * rand ( ) * [gbest ( ) – present ( )]*
Update particle position as the following equation
Present ( ) = Present ( ) + V ( )
End

IV. Problem Formulation

The loss minimization problem has been mathematically formulated and is given by [10]:

Objective I:
Minimize *u(x)*;
Subject to *v(x)* = 0; and *p(x)* < 0; where $x_i < x < x_u$

where *u(x)* is a function of the sum of branch losses, *v(x)* is the functional equality constraints, *p(x)* is functional inequality constraints and the limits of the control variables, x is the state variable vector, x_i and x_u are the lower and upper limits of variable x respectively.

Two objective functions are used in this topic. They can be written as follows

$$u_1(x) = P_L \tag{8}$$

where P_L equal to the sum of line active power losses in the system.

$$u_2(x) = \left\| \begin{matrix} \Delta P \\ \Delta Q \end{matrix} \right\|_2 + P_L \tag{9}$$

The functional equality constraints, *v(x)* is

$$\Delta P_i = P_{Gi} - P_{Di} - P_i \tag{10}$$

$$\Delta Q_i = Q_{Gi} - Q_{Di} - Q_i \tag{11}$$

The inequality constraints, *p(x)* represents system and equipment technical limits

$$V_{\min} \le V \le V_{\max} \tag{12}$$

$$-0.8 X_L \le X_{UPFC} \le 0.2 X_L \, p.u. \tag{13}$$

$$\phi_{\min} \le \phi \le \phi_{\max} \tag{14}$$

$$\partial_{\min} \le \partial_p \le_{\max} \tag{15}$$

$$-100MVAR \le Q_{UPFC} \le 100MVAR \tag{16}$$

where the state variable vector 'X' is defined as

$$X = \begin{bmatrix} V \\ X_{UPFC} \\ \phi \\ \partial \end{bmatrix} \tag{17}$$

At a time one objective function (i.e. either u_1 or u_2) is considered.

Objective II:
Minimize F, where

$$F = \sum_{j=1}^{n} F_{cj}(P_j) \tag{18}$$

where $F_{cj}(P_j)$ is the fuel cost function of unit j and P_j is the real power generated by the unit j , subject to power balance constraints,

$$P_{ld\,\max} = \sum_{j=1}^{n} P_j - P_L \tag{19}$$

where $P_{ld\,\max}$ is the maximum loadability limit and P_L is the sum of line active power losses. The generator constraint is given by,

$$P_{j\min} \le P_j \le P_{j\max} \text{ for } j = 1,2,3,\cdots,n \tag{20}$$

where $P_{j\min}$ and $P_{j\max}$ are the minimum and maximum real power output of generating unit j . The fuel cost is then can be written as

$$F_{cj}(P_j) = a_i P_j^2 + b_i P_j + c_i \tag{21}$$

where a_i , b_i and c_i are the fuel cost coefficients of generating unit j .

IV. Results And Discussion

The proposed algorithm is implemented on Matlab, version 10.2 for solving Optimal Power Flow to determine the optimal location of UPFC and is experimented on modified IEEE 14-bus system. The control variables were considered as both continuous and discrete. The system is having five generators (at buses 1, 2, 3, 6, 8) and three transformers (between buses 6-5, 9-4, 4-7). The operating range of all transformers is set between 0.9-1.05 with a discrete step size of 0.01. The results of the extreme cases (for minimum cost and for minimum real power loss) are presented after executing 100 trial runs for each test case. Using (3)-(6), the sensitivities of modified IEEE 14-bus system were measured. The lines having maximum sensitivities are shown in the Table 1. From Table 1, it can be concluded that real power loading sensitivity c_2^K is more negative (i.e.-191.16) when UPFC is connected between bus 4 and 9. The reactive power loading sensitivity C_3^k is also more negative (i.e. -698.17) for the line 4-9 with UPFC. Therefore, the optimal location of UPFC is chosen when it is connected between buses 4-9. After identifying the suitable buses a load flow is performed using GA and PSO techniques respectively and the results are given in Table 2 and 3. The total system power losses are also given with and without UPFC.

Table 1: Line Loss Sensitivity Indices of Modified IEEE 14 Bus Systems

Line-k (i to j)	C_1^k	C_2^k	C_3^k	C_4^k
6-13	-31.34	-68.789	-352.28	139.95
4-9	-15.98	-191.16	-698.17	311.16
4-2	-78.23	-80.569	-158.94	123.12
4-3	-84.47	-82.884	-219.69	164.92
1-5	87.45	97.828	-232.76	172.68
2-3	-27.72	-67.72	-365.13	69.64

Table 2: Generation Cost and Active Power Loss in PSO Technique

Variables	Without UPFC		With UPFC	
	Generation cost	Active power loss	Generation cost	Active power loss
P_{G1}	48.3744	16.2532	50.9052	17.6351
P_{G2}	56.4131	38.2815	57.8389	37.2275
P_{G3}	32.6271	41.6905	31.7152	40.2483
P_{G6}	46.1305	35.8461	46.1492	36.8415
P_{G8}	29.4743	45.6352	28.0961	44.3614
Total generation cost	683.210		651.817	
Line/Bus	-		4-9	

Table 3: Parameter Values for GA and PSO Technique

Parameter	Modified IEEE 14 Bus	
	GA method	PSO method
No of variables	24	24
Population size	50	50
No of iterations	100	100
C_1	-	2
C_2	-	2
W	-	0.3-0.95
Crossover probability	0.9	-
Mutation probability	0.003	-

Table 4: Comparative Performance of Different Case Studies with GA and PSO Techniques

Case study	GA method	PSO method
Initial loss (p.u)	0.9216	0.5806
Final loss (p.u)	0.0627	0. 0124
Total loss reduction (p.u)	0.8589	0. 5682
Simulation time in sec	297.5180	254.1740

Table 5: Total Active Power Loss With and Without UPFC in PSO Technique

Line k (i to j)	Total loss reduction (p.u)	
	With UPFC	Without UPFC
4-9	**0.5201**	**0.8429**
13-6	0.5353	0.8229
4-3	0.5732	0.8432
6-5	0.5542	0.8169
2-3	0.5425	0.8509

Table 6: Total Active Power Loss With and Without UPFC in GA Technique

Line k (i to j)	Total loss reduction (p.u)	
	With UPFC	Without UPFC
4-9	**0.8721**	**1.1535**
13-6	0.8431	1.1017
4-3	0.8214	0.8821
6-5	0.8742	0.9140
2-3	0.8514	0.9310
11-6	0.8123	0.9215

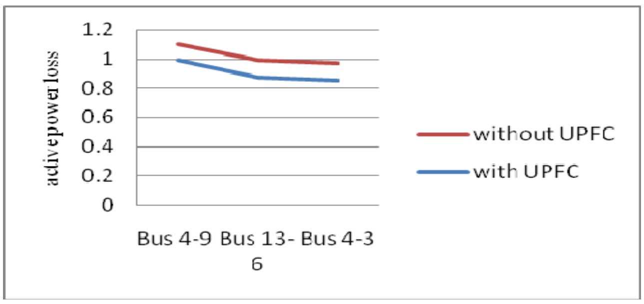

Fig. 3: Active power loss vs bus number

Table 7: Power Flows with UPFC for PSO Technique

Branch	From	To	Losses	
			P (MW)	Q (MVar)
1	1	2	5.977	16.45
2	1	5	3.487	13.34
3	2	3	2.453	9.53
4	2	4	1.910	6.72
5	2	5	1.092	3.54
6	3	4	0.813	1.74
7	4	5	0.657	0.52
8	4	7	0.211	0.84
9	**4**	**9**	**0.012**	**2.82**
10	5	6	0.019	3.44
11	6	11	0.174	0.99
12	6	12	0.071	0.37
13	6	13	0.283	0.58
14	7	8	0.022	0.51
15	7	9	0.349	0.77
16	9	10	0.459	0.88
17	9	14	0.832	0.02
18	10	11	0.977	0.45
19	12	13	0.048	0.52
20	13	14	0.161	0.73

Table 8: Power Flows without UPFC for PSO Techniques

	From	To	Losses	
			P (MW)	Q (MVar)
1	1	2	6.213	17.50
2	1	5	3.800	13.71
3	2	3	2.832	9.61
4	2	4	1.541	5.14
5	2	5	1.129	3.34
6	3	4	0.790	1.23
7	4	5	0.541	0.74
8	4	7	0.342	0.91
9	**4**	**9**	**0.064**	**2.02**
10	5	6	0.041	3.19
11	6	11	0.382	1.20
12	6	12	0.621	0.83
13	6	13	0.642	0.91
14	7	8	0.030	0.63
15	7	9	0.381	0.92
16	9	10	0.481	0.90
17	9	14	0.612	0.83
18	10	11	0.713	0.53
19	12	13	0.972	0.45
20	13	14	0.481	0.61

IV. Conclusion

In this paper, the appropriate position of UPFC was identified using line loss sensitivity index. GA and PSO techniques separately applied to achieve minimum active power loss while satisfying the power system constraints. The sensitivity index has been used for optimal placement of UPFC to minimize active power loss using GA and PSO techniques. The proposed methodology has been applied and tested under simulated condition on modified IEEE 14-bus system. The problem has been formulated as true multi objective optimization problem with competing and non-commensurable objectives such as generation cost and active power loss. It is clear from the results obtained by different trials that PSO is a better technique than GA for active power loss minimization problem in a power system network. It has been observed that the PSO has the ability to converge to a better quality solution and possesses better convergence characteristics and robustness than GA. Furthermore, PSO takes less simulation time than GA. From the results it is concluded that the system performs better when the UPFC is connected at its optimal location.

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