Journal of Engineering and Applied Sciences 2 (10): 1576-1580, 2007
ISSN: 1816-949X

A New Method for Optimal Location of Facts Controllers Using Genetic Algorithm

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Abstract: This study presents a novel method for optimal location of FACTS controllers in a multi machine power system using Genetic Algorithm(GA). Using the proposed method, the location of FACTS controller, their type and rated values are optimized simultaneously. Among the various FACTS controllers, Thyristor Controlled Series Compensator (TCSC) and Unified power Flow Controller (UPFC) are considered. The proposed algorithm is an effective method for finding the optimal choice and location of FACTS controller and also in minimizing the overall system cost, which comprises of generation cost and investment cost of FACTS controller using GA and conventional Newton Raphson's power flow method. A VC++ coding is developed for Genetic Algorithm. In order to verify the effectiveness of the proposed method, IEEE 9 bus system is used. Different operating conditions of the power system are considered for finding the optimal choice and location of FACTS controllers. The proposed algorithm is an effective and practical method for the optimal allocation of FACTS controllers.

Key words: Optimal Power Flow (OPF), Flexible AC Transmission System (FACTS), Genetic Algorithm (GA), Newton Raphson's (NR) power flow

INTRODUCTION

In present days with the deregulation of electricity market, the traditional practices of power system have been completely changed. Better utilization of the existing power system resources to increase capabilities by installing FACTS controllers (Gerbex *et al*., 2001) with economic cost becomes essential.

The parameters such as transmission line impedances, terminal voltages and voltage angle can be controlled by FACTS controllers in an efficient way. The benefits brought about FACTS include improvement of system dynamic behavior and enhancement of system reliability. However, their main function is to control of power as ordered (Lie and Deng, 1997; Chug and Li, 2001).

A few research works (Duan *et al*., 2000; Gyugyi *et al*., 1995) were done on the impact of FACTS controllers on improving static performance of the power system. There is also a great need for studying the impact of FACTS controllers on optimal power flow. The investment costs of FACTS controllers and their impact on the power generation cost are also reported (Gyugyi *et al*., 1999). Many researches were made on the optimal choice and the location of FACTS controllers (Gerbex *et al*., 2001; Lie and Deng, 1997; Patemi *et al*., 1999).

The objective of this study, is to develop an algorithm to simultaneously find the real power allocation of generators and to choose the type and find the best location of FACTS controllers such that overall system cost which includes the generation cost of power plants and investment cost of FACTS are minimized using Genetic Algorithm and conventional Newton Raphson's power flow analysis.

STATIC MODEL OF FACTS CONTROLLERS

Among the various FACTS controllers, Thyristor Controlled Series Compensator (TCSC) and Unified Power Flow Controller (UPFC) are considered in this study. The detailed models are discussed below.

TCSC: The TCSC can serve as the capacitive or inductive compensation, respectively by modifying the reactance of the transmission line. In this study, the reactance of the transmission line is adjusted by TCSC directly. The rated value of TCSC is a function of the reactance of the transmission line where the TCSC is located.

$$X_{ij} = X_{Line} + X_{TCSC},\ X_{TCSC} = rtcsc.\ X_{Line} \qquad (1)$$

Where, X_{Line} is the reactance of the transmission line and rtcsc is the coefficient which represents the compensation degree of TCSC.

To avoid over compensation, the working range of the TCSC is between 0.7 X_{Line} and 0.2 X_{line}

$$r\ tcsc_{min} = -0.7,\quad r\ tcsc_{max} = 0.2 \qquad (2)$$

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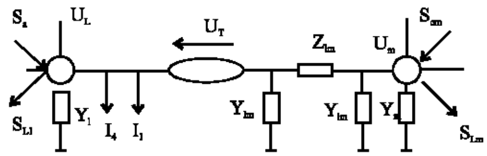

Fig. 1: UPFC is connected between node l and m, with exciting transformer at node l

UPFC: The UPFC is a combination of shunt and series controller. It has three controllable parameters namely, the magnitude of the boosting injected voltage (U_T), phase of this voltage($\emptyset_T$) and the exciting transformer reactive current(I_q)

When an UPFC is installed in the power system as depicted in Fig. 1 i.e., the exciting transformer of UPFC is directly connected to bus l. In Fig. 1, Z_{lm} and Y_{lm} denote the parameters of transmission line l-m. Y_l and Y_m denote the respective shunt admittance for bus l and bus m.

When the UPFC is placed in the transmission line connected between node l and m, the load flow equations can be expressed as follows (Warliang and Ngan, 1997).

$$P_{Gi} - P_{Li} = \sum_{j \in i} U_i U_j (G_{ij} \cos\delta_{ij} + B_{ij} \sin\delta_{ij}) \quad (3)$$

$$Q_{Gi} - Q_{Li} = \sum_{j \in i} U_i U_j (G_{ij} \sin\delta_{ij} - B_{ij} \cos\delta_{ij}) \quad (4)$$

$$i = 1,2....n; \text{ but } i \neq 1, m$$

$$P_{Gl} - P_{Ll} = \sum_{j \in i} U_l U_j (G_{lj} \cos\delta_{lj} + B_{il} \sin\delta_{lj}) + \Delta P_l \quad (5)$$

$$Q_{Gl} - Q_{Ll} = \sum_{j \in i} U_l U_j (G_{lj} \sin\delta_{lj} + B_{lj} \cos\delta_{lj}) + \Delta Q_l \quad (6)$$

$$P_{Gm} - P_{Lm} = \sum_{j \in i} U_m U_j (G_{mj} \cos\delta_{mj} + B_{mj} \sin\delta_{mj}) + \Delta P_m \quad (7)$$

$$Q_{Gm} - Q_{Lm} = \sum_{j \in i} U_m U_j (G_{mj} \sin\delta_{mj} - B_{mj} \cos\delta_{mj}) + \Delta Q_m \quad (8)$$

Where n is the total number of nodes of the power system:

P_{Gi}, Q_{Gi}, P_{Li} and Q_{Li} ($\forall$ i) are the respective real and reactive power of generator and load of node i.

U_i δi ($\forall$ i, j) are respective magnitude and phase angle of the voltage of node i.

j$\in$i signifies that bus j is connected to bus i;

$$\delta_{ij} = \delta_i - \delta_j \ (\forall \text{ i, j})$$

G_{ij} and B_{ij} ($\forall$ i,j) are the respective real part and imaginary part of Y_{ij} which represents the elements of the network admittance matrix. Here Y_{ij} is exactly the same as that of the network without UPFC.

Δp_l, ΔQ_l, ΔP_m and ΔQ_m are the modified items due to the added UPFC.

The formulae of modification can then be written as

$$\Delta P_l = -U_m U_T[G\cos(\delta_m - \phi_T) - B\sin(\delta_m - \phi_T)] + G_F U_T^2 + 2U_l U_T G_F \cos(\delta_l - \phi_T) \quad (9)$$

$$\Delta Q_l = U_m U_T[G_F \sin(\delta_l - \phi_T) - B_F \cos(\delta_l - \phi_T)] - U_l I_q \quad (10)$$

$$\Delta P_m = -U_m U_T[G\cos(\delta_m - \phi_T) + B\sin(\delta_m - \phi_T)] \quad (11)$$

$$\Delta Q_m = -U_m U_T[G\sin(\delta_m - \phi_T) - B\cos(\delta_m - \phi_T)] \quad (12)$$

Where,

$$G + jB = 1/Z_{1m};$$
$$G_F = g_{1m} + G;$$
$$B_F = b_{1m} + B;$$
$$Y_{lm} = g_{lm} + jb_{lm;}$$

The injected voltage of UPFC has a maximum voltage magnitude of $0.1V_m$,where V_m is the rated voltage of the transmission line where UPFC is installed. The angle of the UPFC can be varied from -180 to +180 degrees.

COST FUNCTION

The objective of this study, is to find simultaneously the optimal generation and optimal choice and location of FACTS controllers so as to minimize the overall cost function, which comprises of generation cost and investment costs of FACTS controllers.

Generation cost function: The generation cost function is represented by a quadratic polynomial as follows:

$$C_2(P_G) = \alpha_0 + \alpha_1 P_G + \alpha_2 P_G^2 \quad (13)$$

Where P_G is the output of the generator (MW) and α_0, α_1 and α_2 are cost coefficients.

Investment costs function of FACTS controllers: Based on the Siemens AG Daase, the cost functions for TCSC and UPFC are developed

The cost functions for UPFC and TCSC are :

$$C_{1UPFC} = 0.0003S^2 - 0.2691S + 188.22 \ (US\$ / kVar) \quad (14)$$

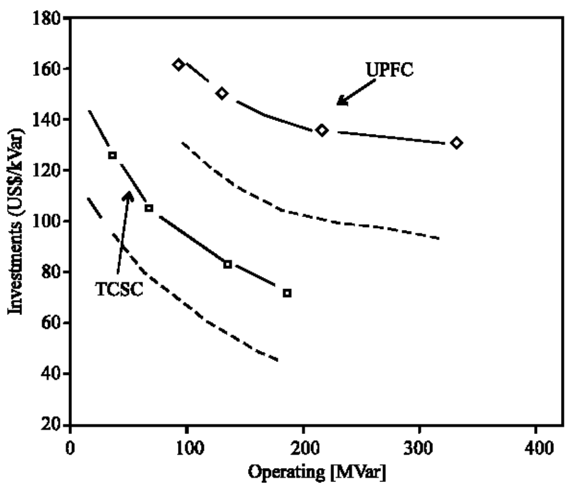

Fig. 2: Cost functions of the FACTS Controllers: TCSC and UPFC

$$C_{1TCSC} = 0.0015S^2 - 0.7130S + 153.75 \text{ (US\$ / kVar)} \quad (15)$$

Where C_{1UPFC} and C_{1TCSC} are in US$/kVar and S is the operating range of the FACTS controllers in kVar.

The cost function for TCSC and UPFC are shown in Fig. 2.

OPTIMAL POWER FLOW WITH FACTS CONTROLLERS

The formulation of the optimal allocation of FACTS controllers can be expressed as follows:

$$\text{Minimise } C_{Total} = C_1(f) + C_2(P_G) \quad (16)$$

$$\text{subjected to } E(f,g) = 0 \quad (17)$$

$$B_1(f) < b_1,\ B_2(g) < b_2 \quad (18)$$

Where

C_{total} : The overall cost objective function which includes the average investment costs of FACTS devices $C_1(f)$ and the generation cost $C_2(P_G)$.

E (f.g) : The conventional power flow equations.

B_1 (f) and B_2 (g) are the inequality constraints for FACTS controllers and the conventional power flow, respectively.

f and P_G are vectors that represent the variables of FACTS controllers and the active power outputs of the generators. g represents the operating state of the power system.

The unit for generation cost is US$/Hour and for the investment cost of FACTS controllers are US$. They must be unified into US$/Hour. Normally the FACTS controllers will be in service for many years. However, only a part of its life time is employed to regulate the power flow. In this study, three years is employed to evaluate the cost function. Therefore, the average value of the investment costs are calculated as follows:

$$C_1(f) = C(f)/\{8760\times3\} \quad 19)$$

As mentioned above, power system parameters can be changed using FACTS controllers. These different parameters derive different results on the objective function. Also, the variation of FACTS locations and FACTS types has also influences on the objective function. Therefore, using the conventional optimization methods are not easy to find the optimal location of FACTS devices, types and control parameters simultaneously. To solve this problem, genetic algorithm is employed in conjunction with conventional NR power flow method.

GENETIC ALGORITHM FOR OPTIMAL POWER FLOW INCORPORATING FACTS CONTROLLERS

Gas are global search techniques based on the mechanism of natural selection and genetics. Without any prior knowledge of the objective function they can search several possible solution simultaneously. Gas are best suited for a complex problems. Moreover, it produces high quality solution.

GA start with random generation of initial population and then the selection, crossover and mutation are proceeded until best population is found. GAs are simple and practical algorithm and easy to be implemented in power system.

Encoding: The objective is to find simultaneously the optimal generation and optimal choice and location of FACTS controllers subjected to equality and inequality constraints. Therefore the configuration of FACTS devices is encoded by four parameters: Active power outputs of generator, type, location and rating of FACTS controllers. The first value of each string corresponds to the active power outputs of generator, second value represents the location the third value represents the type of FACTS controllers 1 for TCSC, 2 for UPFC and 0 for No device. The last value rf represents the rated value of each FACTS controllers. This value ranges between -1 and +1. The real value of each FACTS device is then converted according to the different FACTS model using the following.

TCSC: It has working ranges between -0.7 X_{Line} and 0.2 X_{Line}. Therefore, rf is converted into real degree of compensation rtcsc using the relation rtcsc = rf×0.45-0.25.

UPFC: It has an injected voltage magnitude of 0.1 V_m and the angle of the injected voltages varies between -180 and +180 degrees. Therefore, rf is converted into the working angle range rupfc, using the relation

rupfc = rf×180 degrees

Initial population: The initial population is generated from the following parameters:

N_G : Active power output of generators.
N_{type} : Types of FACTS controllers
$N_{Location}$: Possible location of FACTS controllers.
N_{rated} : Rating of FACTS controllers.
N_{ind} : No. of individual of the population.

For each population, string the first value represents a set of generators real power output which is randomly selected.

The second value represents the type of FACTS controllers which is obtained by randomly drawing number among the selected devices (1, 2, 0).

The third value of each string represents the location of FACTS controllers in the transmission line which is also randomly selected among the existing number of transmission lines in the system.

The fourth value represents the rating of the FACTS controllers again randomly selected between -1 and +1. To obtain the entire initial population the above operation is repeated N_{ind} times.

Decoding: The parameters of the initial population are then decoded to actual values.

Then for a given load demand the Newton Raphson's power flow is performed (Wanlaing and Ngan, 1997).

$$\begin{bmatrix} H & N \\ J & L \end{bmatrix}\begin{bmatrix} \Delta\delta \\ \Delta V/V \end{bmatrix} = \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} \quad (20)$$

After convergence the voltage magnitude and phase angles of the bus voltages are known. Using these the real power loss P_L is calculated using the Eq. (21)

$$P_L = \sum_{i=1}^{n}\sum_{j=1}^{n}(P_i\alpha_{ij}P_j + Q_i\alpha_{ij}Q_j - P_i\beta_{ij}Q_j + P_j\beta_{ij}Q_i) \quad (21)$$

$$\alpha_{ij} = \frac{r_{ij}\cos(\delta_i - \delta_j)}{|v_i|.|v_j|} \quad (22)$$

$$\beta_{ija} = -\frac{r_{ij}\sin(\delta_i - \delta_j)}{|v_i|.|v_j|} \quad (23)$$

Where

r_{jk} = The real components of the elements of the bus impedance matrix.
n = The number of buses.
P_i = The real power at bus i.
Q_i = The reactive power at the bus i.
V_i = The magnitude of the voltage at bus I.

Fitness function: After encoding, the objective function (fitness) is evaluated for each individual of the population. The fitness is a measure of quality which is used to compare different solutions. In this study fitness is defined as follows:

$$\text{Fitness} = \frac{1}{C_{Total} + W(\sum_{i}^{N} P_{Gi} - P_{Di} - P_{Li})} \quad (24)$$

Since the GA can only find the maximum value of the objective, so inverse function is selected to convert the objective function into a maximum one.

Then reproduction, crossover and mutation are applied successively to generate the offspring.

Reproduction: Reproduction is a process where the individual is selected to move to a new generation according to their fitness. The biased roulette wheel selection is employed. The probability of an individual's reproduction is proportional to its part on the biased roulette wheel.

Crossover: The main objective of crossover is to reorganize the information of two different individuals and produce a new one. A single point crossover is applied and probability of crossover is selected as 1.0

Mutation: Mutation is used to introduce some sort of artificial diversification in the population to avoid premature convergence to local optimum.

The above-mentioned operations of selection, crossover and mutation are repeated until the best individual is found.

RESULTS

A VC++ coding is developed for Genetic Algorithm. In order to verify the effectiveness of the proposed method IEEE 9 bus system is used. Different operating conditions are considered for finding the optimal choice and location of FACTS controllers.

Table 1: Optimal choice location and rating of FACTS controllers

Bus	Loading	Rating of device(mvar)	Location	Device type	Remarks
5	Normal loading	0.0	-	No facts devices	-
5	Twice the normal loading	10.166	Line 3	tcsc	Line 3 connects 5th and 6th bus
5	3 Times the normal loading	17.977	Line 4	tcsc	Line 4 connects 3rd and 6th bus 6th bus is connected directly to 5th bus
5	3 Times the normal loading and without generation at bus 3	156.02	Line 4	upfc	Line 4 connects 3rd and 6th bus.6th bus is connected directly to 5th bus
9	Twice normal loading	62.989	Line 2	tcsc	Line 2 connects 4th and 5th bus. 4 and 9th bus are directly connected
9	3 Times the normal loading	96.038	Line 2	upfc	Line 2 connects 4th and 5th bus. 4th and 9th bus directly connected
9	Twice normal loading and without generation at bus 2	47.520	Line 6	upfc	6th line connects buses 7 and 8. 8th bus is connected to 9th bus

The total population size is selected as 150, the mutation probability as 0.01 and crossover probability as 1.0.

Case 1: For the normal loading of IEEE 9 bus system it has been found that No FACTS controllers are required. The generators outputs are 202, 31.6, 86.4, 204, 19 and 75 MW, respectively.

Case 2: When the loading at bus 5 is increased twice it is found that TCSC is selected at transmission line 3. The VAR compensation required is 10.166 MVAR. The generators outputs are 116.4, 124.86, 170, 113, 101 and 157 MW, respectively.

Case 3: When the loading at bus 5 is increased by three times and removing the generation at bus 3 it has been found that UPFC is selected in the transmission line 4 and VAR compensation required is 156.02 MVAR. The generators outputs are 245.3MW, 263.6MW, 0MW, 250MW, 223MW and 183MW, respectively.

Apart from that different loading conditions are considered and the results are given in Table 1.

CONCLUSION

In this study, a genetic algorithm based optimal power flow is proposed to determine the type of FACTS controllers, its optimal location and rating of the devices in power systems and also to simultaneously determine the active power generation for different loading condition. The overall system cost function which includes generation cost of power plants and the investment costs of FACTS controllers are employed to evaluate the power system performance.

The proposed algorithm is an effective and practical method for the allocation of FACTS controllers.

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