BY USING GENETIC ALGORITHM METHOD FOR OPTIMAL LOCATION OF FACTS DEVICES IN THE DEREGULATED POWER SYSTEM

[1] PRAKASH G.BURADE, [2] DR.J.B.HELONDE
[1] Asst.Professor, Nuva College of Engineering & Technology, Nagpur, India
[2] Prof & Principal, Gurunanak College of Engineering & Technology, Nagpur, India

ABSTRACT

The introduction of flexible AC transmission system (FACTS) in a power system improves the stability, reduces the losses, reduces the cost of generation and also improves the loadability of the system. In the proposed work, a non-traditional optimization technique, genetic algorithm is used to optimize the various process parameters involved in introduction of FACTS devices in a power system. The various parameters taken into consideration were the location of the device, their type, and their rated value of the devices. The simulation was performed on a 30-bus power system with various types of FACTS controllers, modeled for steady state studies. The optimization results clearly indicate that introduction of FACTS devices in a right location increases the loadability of the system and genetic algorithm can be effectively used for this kind of optimization.

Keywords: *Genetic Algorithm, Optimization, loadability, FACTS, optimal power flow.*

1. INTRODUCTION

In recent years, with the deregulation of the electricity market, the traditional concepts and practices of power systems are changed. This led to the introduction of Flexible AC Transmission system (FACTS) such as Thyristor Controlled Series Compensations (TCSC), Thyristor controlled phase angle Regulators (TCPR), Unified Power Flow Controllers (UPFC) and Static Var Compensator (SVC). These devices controls the power flow in the network, reduces the flow in heavily loaded lines there by resulting in an increase loadability, low system losses, improved stability of network and reduced cost of production [2] [10] [11] [13], It is important to ascertain the location of these devices because of their significant costs. S.Jerbex et al [4] provides an idea regarding the optimal locations of fact devices, without considering the investment cost of FACTS device and their impact on the generation cost. L.J.Cai et al [5] later studied about the optimal location considering the generation cost of the power plants and investment cost of the Devices.J.baskaran et al [16], discussed optimal location problem by power loss reduction. The main objective of this paper is to develop an algorithm to find and choose the optimal location of FACTS devices based on the Economic saving function, which obtained by energy loss reduction. The different types of FACTS devices and their different location have different advantages. In realizing, for the proposed objective function, the suitable types of FACTS device, their location, and their rated value must be determined simultaneously. This combinatorial analysis problem is solved by Genetic algorithm.

This paper is organized as follows: following the introduction, different FACTS devices mathematical models are described in section II. Then in section III, objective functions are described. In section IV, the genetic algorithms for optimal location of FACTS devices are discussed in detail. The simulation results are given in section V.

2. MATHEMATICAL MODEL OF FACTS DEVICES:

A. FACTS DEVICES:

In an interconnected power system network, power flows obey the Kirchoff's laws. The resistance of the transmission line is small compared to the reactance. Also the transverse conductance is close to zero. The active power transmitted by a line between the buses i and j may be approximated by following relationships:

$$P_{ij} = \frac{V_i V_j}{X_{ij}} \sin\delta_{ij} \quad (1)$$

Where:Vi and Vj are voltages at buses i and j;Xij: reactance of the line; δij: angle between the Vi and Vj.Under the normal operating condition for high voltage line the voltage Vi =Vj and θij is small. The active power flow coupled with θij and reactive power flow is linked with difference between the Vi-Vj. The control of Xij acts on both active and reactive power flows. The different types of FACTS devices have been choose and locate optimally in order to control the power flows in the power system network. The reactance of the line can be changed by TCSC.TCPAR varies the phase angle between the two terminal voltages and SVC can be used to control the reactive power. UPFC is most power full and versatile device, which control line reactance, terminal voltage, and the phase angle between the Buses.In this paper, four different typical FACTS devices have been selected: TCSC, TCPAR, SVC and UPFC. Their block diagrams are shown in Figure 1.

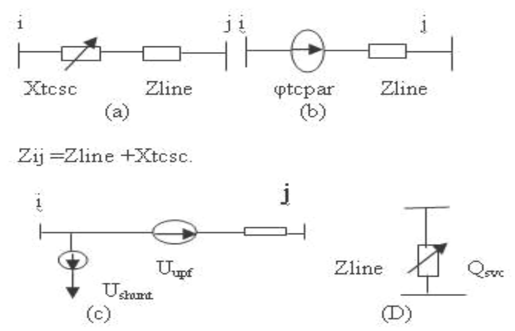

Figure.1 Block diagram of the considered FACTS devices: a) TCSC b) TCPST c) UPFC
d) SVC

The above-mentioned FACTS devices can be applied to control the power flow by changing the parameters of power systems, so that the power flow can be optimized.

B. MATHEMATICAL MODELS:

The power-injected model is a good model for FACTS devices because it will handle them well in load flow computation problem. Since, this method will not destroy the existing impedance matrix Z; it would be easy while implementing in load flow programs. In fact, the injected power model is convenient and enough for power system with FACTS devices. The Mathematical models of the FACTS devices are developed mainly to perform the Steady state research. The TCSC, TCPAR, SVC and UPFC are modeled using the power injection method [4,]-[5][8][13], Furthermore, the TCSC, TCPAR, SVC and UPFC mathematical model are integrated into the model of the Transmission line. Fig: 1 shows a simple transmission line, the parameter are connected between bus i and bus j.the voltages and angles at the buses i and j are Vi, δi and Vj, δj respectively. The real and reactive power flow between the buses i to bus j can be written as

$$P_{ij} = V_i^2 G_{ij} - V_i V_j [G_{ij}\cos(\delta_{ij}) + B_{ij}\sin(\delta_{ij})]. \quad (2)$$

$$Q_{ij} = -V_i^2 (B_{ij}+B_{sh}) - V_i V_j [G_{ij}\sin(\delta_{ij}) - B_{ij}\cos(\delta_{ij})]. \quad (3)$$

Where the $\delta_{ij} = \delta_i - \delta_j$, similarly, the real and reactive power flow between the bus j to bus i is

$$P_{ji} = V_i^2 G_{ij} - V_i V_j [G_{ij}\cos(\delta_{ij}) - B_{ij}\sin(\delta_{ij})]. \quad (4)$$

$$Q_{ji} = -V_i^2 (B_{ij}+B_{sh}) + V_i V_j [G_{ij}\sin(\delta_{ij}) + B_{ij}\cos(\delta_{ij})]. \quad (5)$$

TCSC:

The model of a transmission line with a TCSC connected between the buses i and j is shown n figure: 1. The change in the line flows due to series reactance. The real power injection at buses i and bus j (Pi (com)) and Pj(com)can be expressed as

$$P_{i(com)} = V_i^2 \Delta G_{ij} - V_i V_j [\Delta G_{ij}\cos(\delta_{ij}) + \Delta B_{ij}\sin(\delta_{ij})] \quad (6)$$

$$P_{j(com)} = V_j^2 \Delta G_{ij} - V_i V_j [\Delta G_{ij}\cos(\delta_{ij}) - \Delta B_{ij}\sin(\delta_{ij})] \quad (7)$$

Similarly, the reactance power injected at bus i and j (Qi (com)) can be expressed as

$$Q_i(com) = -V_i^2 \Delta B_{ij} - V_iV_j [\Delta G_{ij}\sin(\delta_{ij}) - \Delta B_{ij}\cos(\delta_{ij})] \quad (8)$$

$$Q_j(com) = -V_j^2 \Delta B_{ij} + V_iV_j [\Delta G_{ij}\sin(\delta_{ij}) + \Delta B_{ij}\cos(\delta_{ij})] \quad (9)$$

Where,

$$\Delta G_{ij} = \frac{X_c R_{ij}(X_{tcsc} - 2X_{ij})}{(R_{ij}^2 + X_{ij}^2)(R_{ij}^2 + (X_{ij} - X_{tcsc})} \quad (10)$$

$$DB_{ij} = \frac{-X_{tcsc}(R_{ij}^2 - X_{ij}^2 + X_{tcsc}X_{ij})}{(R_{ij}^2 + X_{ij}^2)(R_{ij}^2 + (X_{ij} - X_{tcsc})} \quad (11)$$

TCPAR:

The voltage angle between the buses i and j can be regulated by TCPAR.The model of a TCPAR with transmission line as shown in fig.1. The injected real and reactive power at buses i and j having the phase shifter are

$$P_i(com) = -V_i^2 S^2 G_{ij} - V_iV_jS [G_{ij}\sin(\delta_{ij}) - B_{ij}\cos(\delta_{ij})] \quad (12)$$

$$P_j(com) = -V_iV_jS [G_{ij}\sin(\delta_{ij}) + B_{ij}\cos(\delta_{ij})] \quad (13)$$

$$Q_i(com) = -V_i^2 S^2 B_{ij} + V_iV_jS [G_{ij}\cos(\delta_{ij}) + B_{ij}\sin(\delta_{ij})] \quad (14)$$

$$Q_j(com) = -V_iV_jS [G_{ij}\cos(\delta_{ij}) - B_{ij}\sin(\delta_{ij})] \quad (15)$$

Where, $S = (\tan\varphi^* \ tcpar)$

UPFC:

A series inserted voltage and phase angel of inserted voltage can model the effect of UPFC on network. The inserted voltage has a maximum magnitude of Vt=0.1Vm, where the Vm is rated voltage of the transmission line, where the UPFC is connected. It is connected to the system through two coupling transformers [8,113].The real and reactive power injected at buses i and j can expressed as follows

$$P_i(com) = -V_t^2 G_{ij} - 2V_iV_jG_{ij}\cos(\varphi_{upfc} - \delta_{ij}) + V_iV_j [G_{ij}\cos\varphi_{upfc} + B_{ij}\sin\varphi_{upfc}]. \quad (16)$$

$$Q_i(com) = V_iV_j[G_{ij}\sin(\varphi_{upfc} - \delta_{ij}) + B_{ij}\sin\varphi_{upfc}]. \quad (17)$$

$$P_j(com) = V_jV_t [G_{ij}\cos\varphi_{upfc} - B_{ij}\sin\varphi_{upfc}]. \quad (18)$$

$$Q_j(com) = -V_tV_j [G_{ij}\sin\varphi_{upfc} + B_{ij}\cos\varphi_{upfc}]. \quad (19)$$

SVC:

The primary purpose of SVC is usually control of voltages at weak points in a network. This may be installed at midpoint of the transmission line. The reactive power output of an SVC can be expressed as follows:

$$Q_{svc} = V_i(V_i - V_r) / X_{sl}. \quad (18)$$

Where, Xsl is the equivalent slope reactance in p.u.equal to the slope of voltage control characteristic, and Vr are reference voltage magnitude. The exact loss formula of a system having N number of buses is [1].

$$P_{ltc} = \sum_{J=1}^{N} \sum_{k=1}^{N} [\alpha_{jk}(P_jP_k + Q_jQ_k) + \beta_{jk}(Q_jP_k - P_jQ_k)]. \quad (19)$$

Where Pj, Pk and Qj, Qk respectively, are real and reactive power injected at bus-j and α_{jk}, β_{jk} are the loss coefficients defined by

Where

$$\alpha jk = \frac{Rjk}{ViVk} \cos(\delta j - \delta k) \quad (20)$$

$$\beta jk = \frac{Rjk}{ViVk} \sin(\delta j - \delta k). \quad (21)$$

Where Rjk is the real part of the j-kth element of [Zbus] matrix. The total loss if a FACTS device, one at a time, is used, can be written as follows [12].

$$Pl\,k = (Pl\,kc - [Pi\,(com) + Pj\,(com)]. \quad (22)$$

More than one device used at time, can be expressed as

$$Pl\,k = (Pl\,kc - \sum_{d=1}^{Nd} [Pi\,(com) + Pj\,(com)]) \quad (23)$$

Where, Nd is number of device is to be located at various lines.

3. OBJECTIVE FUNCTION:

The aim is that to utilize the FACTS device for optimal amount of power in a system is to supply without overloaded line and with an acceptable voltage level. The optimal location of FACTS device problem is to increases as much as possible capacity of the network.i.e loadability. In this work, the FACTS devices have been considered to Economic saving function, which obtained by energy loss, it requires calculation of total real power losses at the day and light load levels.

Objective function is,

Min F (u) is

$$PL\,(V,d,S) = \sum_{i=1}^{N} PLt*Eloss*\Delta T - Cin] \quad (24)$$

Subject to :

$$F\,(b, v) = 0$$

$$F1(s) < M1,$$

$$F2\,(v) < M2$$

Where, u- set of parameters that indicate the location, devices and rated values (b, v): conventional power flow equations, and ΔT – time duration. Loss is energy loss cost. in is investment cost of FACTS device.

F1(s) <M1, and F2 (v) <M2 are inequality constraints for FACTS devices, and conventional power flows.

The FACTS devices can be used to change the power system parameters. These parameters derive different results on the objective function (1). Also various FACTS device locations, rated value and types have also influences on the objective function. The above-mentioned parameters are very difficult to optimize simultaneously by conventional optimization methods. To solve this type of combinatorial problem, the genetic algorithm is employed. The genetic algorithms are well developed and utilized effectively for this work. The C computer coding are developed and for simulated.

4. GENETIC ALGORITHM:

Heuristic methods may be used to solve complex optimization problems. Thus, they are able to give a good solution of a certain problem in a reasonable computation time, but they do not assure to reach the global optimum [3]-[4]-[5]. In case of GAs (Genetic Algorithm) are global search technique, based on the mechanisms of natural selection and genetics; they can search several possible solutions simultaneously.

The GAs start with random generation of initial population and than the selection, crossover and mutation are produced until the best population is found.

Encoding:

The main objective of the optimization is to find the best locations for the given number of FACTS devices within the defined constrains. The configuration of FACTS devices is obtained by three parameters: the location of the devices, their types and their rated values. [4,5]. Each individuals is represented by n-facts number of strings, i.e. number of FACTES devices to be used this optimization problem. The first values of the each string indicate the location information. Only one device in a transmission line, the second value of the string is represent the type of the devices: TCSC for 1, TCPAR for 2, SVC for 3, UPFC for 4 and zero for no device is connected. The last value stands for rated value of the each device. According to the model of the FACTS devices, the rated values (RV) of each FACTS device is converted into the real compensation as follows:

TCSC: The TCSC has a working rang between -0.8 Xij and 0.2 Xij, where Xij is the reactance of the transmission line, where the TCSC installed.

Xtcsc = RV * 0.45 -0.25.

TCPAR: The working range of the TCPAR is between the -5 degrees to +5 degrees.

jtcpar =RV *5(degree).

SVC: The working range of the SVC is between -100Mvar and +100Mvar. The SVC has been considered as a reactive power sources with the above limit.

Vsvc= RV ´ 100 (Mvar).

UPFC: The working range of the UPFC is between -180 degrees to +180 degrees.

jupfc = RV ´ 180(degree).

5. INVESTMENT COST:

The different FACTS devices cost function is developed by the based on the Siemens AG Database [15]. The cost function of SVC, TCSC and UPFC are related to operating ranges but, incase of TCPAR is depends on the operating voltage and current of the circuits, it is fixed, where it is located, the cost function can expressed as

Cin= T-limit + installation cost, where T-limit is thermal limit of the line.

The cost function for SVC, TCSC and UPFC is:

Cinsvc=0.0003S2.3051S+127.38(US$/Kvar). (25)

Cintcsc =0.0015S2 –.7130S+153.75(US$/Kvar). (26)

Cinupfc =0.0003S2 –.2691S+188.22(US$/Kvar). (27)

Where S is the operating rating of the FACTS devices in Mvar.and Cinsvc, Cintcsc, are in US$/Kvar.

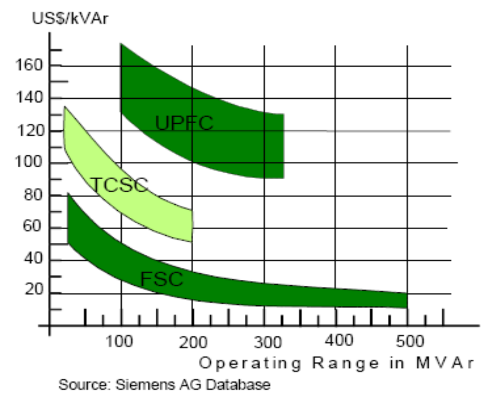

Figure 2: investment cost curve.

6. INITIAL POPULATION:

The initial population is generated from the following parameters [4]-[5], NFACTS is the number of FACTS devices to be located, the possible location of the devices i.e. Locations, types of the devices i.e. N types, and Nind is the number of individuals of the population. The first, a set of NFACTS numbers of strings are produced. For each string, the first value is randomly chosen from the possible locations Nlocation .The second value, which represented the types of FACTS devices, is obtained by randomly drawing numbers among the selected devices. The third value of each string, which contains the rated values of the FACTS devices, is randomly selected between the -1 and +1. To obtain the entire initial population, the above operations are repeated Nind times.

The objective function is computed for every individuals of the population. In our case, the objective function is defined in order to quantify the impact of the FACTS devices on the state of the power system network. The inverse of the objective function is used to compute the fitness value of each individual in the population.

Fitness = 1/ Objective function+1. **(**28)

Reproduction:

The biased roulette wheel selection [3]-[4]-[5] is used in this paper for reproduction, According to their fitness values; the individual is selected to move to a new generation.

Crossover:

Crossover is technique, which is used to rearrange the information between the two different individuals and produce new one. In this paper a two-point crossover is employed and the probability (Pc) of the crossover is 0.75.

Mutation:

The probability of mutation is less than 0.05. Mutation is used to random alteration of bits of string position. The bit will be changed from ±0.5. The above process summarized given below in the flowchart.

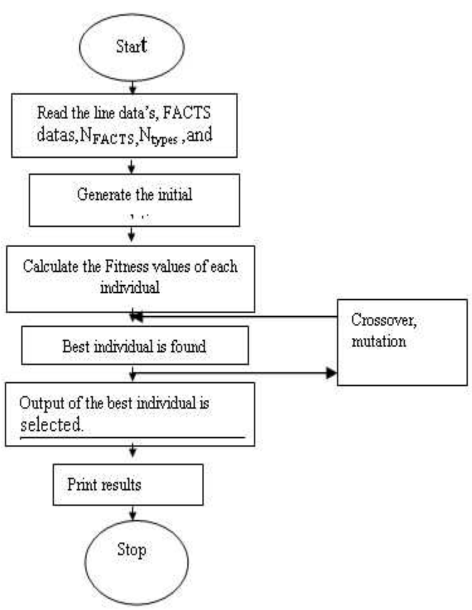

Figure.3 Flow-Chart of GA

SIMULATION TOOL:

Power flows are solved with help of AU Power software package. Simulation was carried out on IEEE 30 Bus test system, it consists of 30 Bus, 41 lines, generator are modeled as PV-node, loads are modeled as PQ- node, the line is modeled using the classical- Õ scheme**.**

7. SIMULATION RESULTS:

The modified IEEE 30 bus test system as shown in fig 4 is used to verify the effectiveness of the proposed algorithm. Whose line and load data can be found in [14]. In this paper, the FACTS device location considered Economic saving function, which obtained by energy loss reduction. The different operating conditions are simulated for the optimal location of FACTS devices problem; reducing the transmission real power loss changes the transmission line capacity. In case of single device optimization: the simulation results are (shown in Table1) TCSC and SVC provide relatively less additional reduction in total active power loss while TCPAR provides 7% more reduction, and it significantly reduces the total real power loss in MW and increase the revenue saving per day as shown in table 4.

The FACTS device not only reduces the real power loss but also improves the loadability, stability of the system and improves the voltage. The Table2 shows the results of voltage increases due to location of FACTS devices in a network. Fig 3 shows the number of devices required to reduce the total real power loss of the system. From the results declared that, the UPFC effectively reduces the losses up to 89-90% of the total loss, and incase of, TCSC, TCPAR, and SVC reduces the losses up to 75%, 70-73% and 55% of total power loss reduction respectively. Less number of devices used is to obtain 89-90% of loss reduction by UPFC, but for other cases the number of devices will be increased. From the results it is clear that UPFC is the most powerful FACTS device while comparing other devices. Since the initial investment cost of UPFC is very high. Other devices like: TCSC, TCPAR, and SVC.

Fig.5 IEEE 30 Bus Topology

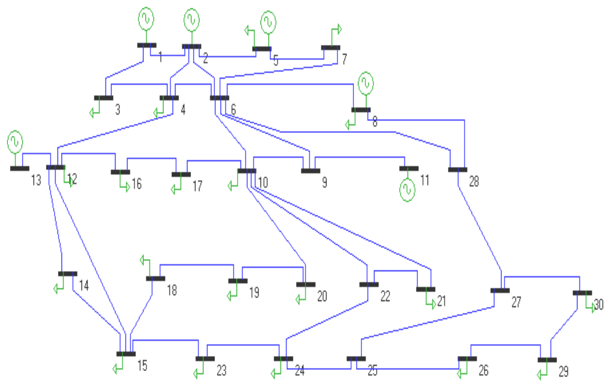

Table 1: Energy Loss Cost

Load levels	Cost [$/KWh]
Day load	0.60
Light load	0.44

Table 2: Economic Saving Cost

Device	Economic saving/day. (Day load)	Economic saving/day (Light load)
1.TCSC	$0.3368	$0.3105
2.SVC	$0.3204	$0.2818
3.TCPAR	$0.5181	$0.4843
4.UPFC,Vt=0.03.	$0.5323	$0.4891

Table3: Shows the Voltage Difference After And Before Location of FACTS Devices

BEFORE		AFTER	
Bus 1	1.060	Bus 1	1.060
Bus 25	0.94866	Bus 25	0.98866
Bus 26	0.92965	Bus 26	0.949645
Bus 29	0.92991	Bus 29	0.9301
Bus 30	0.91747	Bus 30	0.91747

Table 4: Simulation Results

From line	To line	Device-Type	Rated value	Total Power loss	%Power loss reduction
2	5	TCSC	18% X Line	0.3268	14.32%
24	25	SVC	9.8 MVAR	0.3268	13.62%
9	6	TCPAR	3^0 degree	0.3268	22.02%

8. CONCLUSION:

In this paper, the proposed algorithm is to determine the location of given number of FACTS devices in a power system; their type and rated value are simultaneously optimized. Four different type of device are simulated: TCSC, TCPAR, SVC and UPFC. The overall system real power loss reduction, significantly improves the system performance. The simulation results certify that, the efficiency of the proposed algorithm, also simultaneously optimize the location, type and rated value of the device. This algorithm is suitable to search several possible solutions simultaneously. Further, this algorithm is practical and easy to be implemented into the power system.

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