Genetic Algorithm Applied to Optimal Location of FACTS Devices in a Power System

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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 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 modified IEEE 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]. The main objective of this paper is to develop an algorithm to find and choose the optimal location of FACTS devices.

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 2. Then in section 3, objective functions are described. In section 4, the genetic algorithms for optimal location of FACTS devices are discussed in detail. The simulation results are given in section 5.

2. Mathematical Model of FACTS Devices

In an interconnected power system network, power flows obey the load flow calculation. 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.

$$P_{ij} = \frac{V_i . V_j}{X_{ij}} \sin \delta_{ij}$$

Where V_i and V_j are voltages at buses *i* and *j*, X_{ij} reactance of the line, δ_{ij} angle between the V_i and V_j.

Under the normal operating condition for high voltage line the voltage $V_i = V_j$ and δ_{ij} is small. The active power flow coupled with δ_{ij} and reactive power flow is linked with difference between the $V_i - V_j$. The control of X_{ij} 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 powerfull and versatile device, which control line reactance, terminal voltage, and the phase angle between the Buses.

In this paper, two different typical FACTS devices have been selected, TCSC and SVC. Their block diagrams are shown in Fig 1.

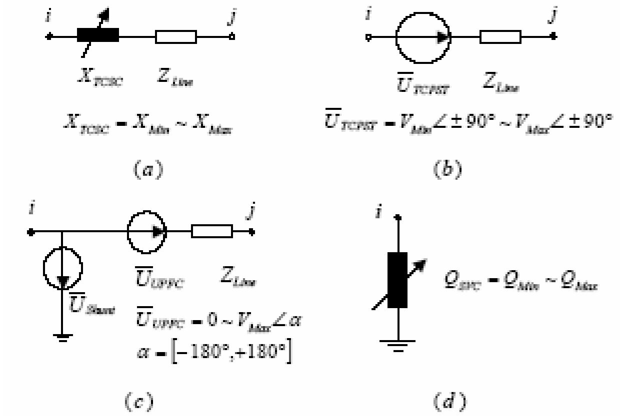

Fig.1 Block diagram of the considered FACTS devices: a. TCSC b. TCPST c. UPFC d. SVC

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.

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 and SVC are modeled using the power injection method [4,5,8,13]. 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:

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

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

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

TCSC

The model of a transmission line with a TCSC connected between the buses *i* and *j* is shown in fig 1. The change in the line flows due to series reactance, real power injection at buses *i*, P_{icom} and bus *j*, P_{jcom} can be expressed as:

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

Similarly, the reactive power injected at bus i, (Q_{icom}) and bus j, (Q_{jcom}) can be expressed as:

$$Q_{icom} = -V_i^2 \Delta B_{ij} - V_i . V_j [\Delta G_{ij} \sin(\delta_{ij}) - \Delta B_{ij} \cos(\delta_{ij})]$$
$$Q_{jcom} = -V_i^2 \Delta B_{ij} + V_i . V_j [\Delta G_{ij} \sin(\delta_{ij}) + \Delta B_{ij} \cos(\delta_{ij})]$$

Where

$$\Delta G_{ij} = \frac{X_C R_{ij} (X_{TCSC} - 2X_{ij})}{(R_{ij}^2 + X_{ij}^2)(R_{ij}^2 + (X_{ij} - X_{TCSC})^2)}$$
$$\Delta B_{ij} = \frac{-X_{TCSC} (R_{ij}^2 - X_{ij}^2 + X_{TCSC} X_{ij})}{(R_{ij}^2 + X_{ij}^2)(R_{ij}^2 + (X_{ij} - X_{TCSC})^2)}$$

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:

$$Q_{SVC} = \frac{V_i\left(V_i - V_r\right)}{X_{eq}}$$

Where, X_{eq} 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].

$$P_{loss} = \sum_{j=1}^{N}\sum_{k=1}^{N}\left[\alpha_{jk}\left(P_j P_K + Q_j Q_k\right) + \beta_{jk}\left(Q_j P_k - P_j Q_k\right)\right]$$

Where Pj, Pk and Qj, Qk respectively, are real and reactive power injected at bus j and αjk, βjk are the loss coefficients defined by:

$$\alpha_{jk} = \frac{R_{jk}}{V_j V_k}\cos\left(\delta_j - \delta_k\right)$$

$$\beta_{jk} = \frac{R_{jk}}{V_j V_k}\sin\left(\delta_j - \delta_k\right)$$

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

$$P_{lk} = P_{loss} - \left[P_{icom} + P_{jcom}\right]$$

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

$$P_{lk} = P_{loss} - \sum_{d=1}^{N_d}\left[P_{icom} + P_{jcom}\right]$$

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

$$P_L\left(V, \delta, S\right) = \sum_{i=1}^{N}\left[P_{Lt} \times E_{loss} \times \Delta T - C_{in}\right]$$

Subject to

$$F(b, v) = 0$$
$$F_1(s) < M_1$$
$$F_2(v) < M_2$$

Where, u set of parameters that indicates the location, devices and rated values.

F (b, v): conventional power flow equations

ΔT: time duration

E_{loss}: energy loss cost

C_{in} : investment cost of FACTS device

$F_1(s) < M_1$, and $F_2(v) < M_2$ 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. 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 Matlab computer software 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 GA are global search technique, based on the mechanisms of natural selection and genetics, they can search several possible solutions simultaneously.

The GA start with random generation of initial population and than 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 FACTS 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, SVC for 2, 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.

$X_{TCSC} = RV \times 0.45 - 0.25.$

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

Vsvc= RV × 100 (Mvar).

Investment cost

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

$C_{in} = T_{limit} + installation\ cost$

where T_{limit} is thermal limit of the line.

The cost function for SVC, TCSC and UPFC is:

$$C_{inSVC} = 0.0003S^2 - 0.3051S + 127.38(US\$/K\text{var})$$

$$C_{inTCSC} = 0.0003S^2 - 0.2691S + 153.75(US\$/K\text{var})$$

$$C_{inUPFC} = 0.0003S^2 - 0.2691S + 188.22(US\$/K\text{var})$$

Where S is the operating rating of FACTS devices in Mvar, and C_{inSVC}, C_{inTCSC} are in US$/Kvar.

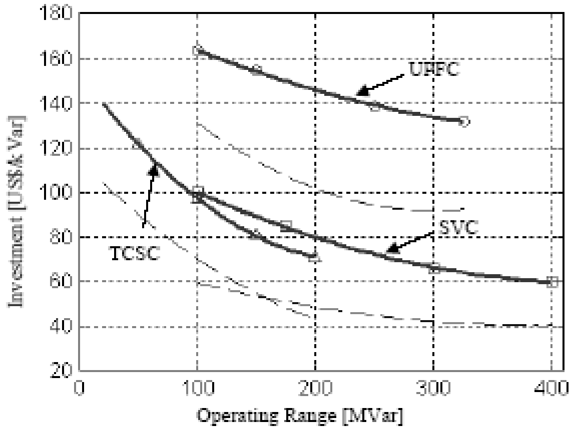

Fig 2: investment cost curve

Initial population

The initial population is generated from the following parameters [4,5]. N_{FACTS} is the number of FACTS devices to be located, the possible location of the devices i.e. $N_{location}$, types of the devices i.e. N_{types}, and N_{ind} is the number of individuals of the population. The first, a set of N_{FACTS} numbers of strings are produced. for each string, the first value is randomly chosen from the possible locations $N_{location}$ .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 N_{ind} 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.

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.

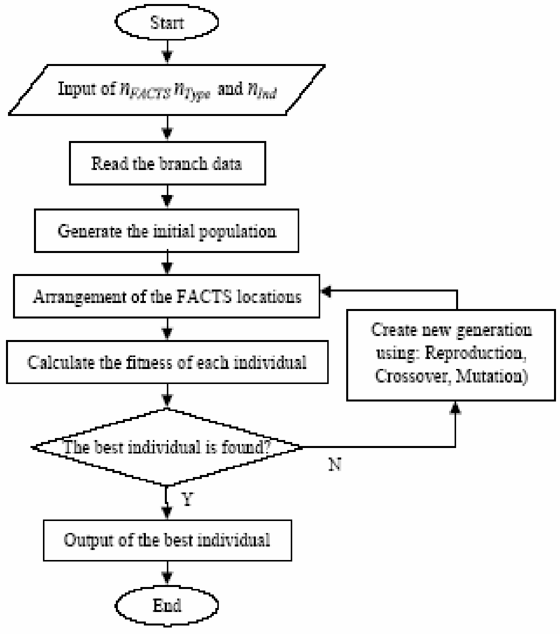

Fig 3. Genetic Algorithm flowchart

5. Simulation Tool

Power flows are solved with MATLAB Power software package. Simulation was carried out on modified 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 π scheme.

Simulation Results

The modified (without shunt capacitors) IEEE 30 bus test system 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.

Case 1: in case one SVC employed, results shown that power loss decreases and improved voltage profile.

Case 2: in case one SVC and one TCSC employed, results shown active power loss decreases but reactive loss and voltage profile don’t varied.

Table 1. simulation Loss results

with SVC		**without FACTS (Loss)**		**with SVC and TCSC**	
MW	**Mvar**	**MW**	**Mvar**	**MW**	**Mvar**
17.695	22.3	17.869	24.862	17.979	14.145

SVC installed at bus 24 with 25 Mvar

SVC installed at bus 24 with 25 Mvar and TSCS at line 1-3 with %5399 Xline

Table 2. simulation voltage results

Bus no	whitout FACTS		with SVC		with SVC & TCSC	
29	0.99	-17.304	1.019	-17.239	1.018	-15.306
30	0.978	-18.206	1.008	-18.1	1.007	-16.167

6.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. Two different type of device are simulated, TCSC and SVC. 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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