Localization of FACTS Devices for Optimal Power Flow Using Genetic Algorithm

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Abstract—**This paper presents about the effective localization of the FACTS (Flexible AC Transmission Systems) devices in power system by a global search GA (Genetic Algorithm) technique. Ultimate goal is to improve the stability of power system as well as to reduce the generation cost, transmission losses by increasing loadability and improving voltage profile with introduce FACTS device at the most effective region. This method is employed by considering the cost of FACTS and their optimal utilization in the system. Optimal location of FACTS , their types and rated values are optimized simultaneously. Three FACTS devices such as TCSC, TCPAR and SVC are simulated in this study. Simulation is carried out on IEEE30 bus and IEEE 118 bus power system with different increased load-ability. We search the efficiency of this method on the basis of power generation cost, FACTS investment cost and transmission loss reduction. The employed algorithm is emerged as an effective and practical method for the choice and allocation of FACTS in large power systems.**

Keywords—FACTS devices, Genetic Algorithm (GA), Optimal Power Flow (OPF), Improved loadability, Load Flow.

I. INTRODUCTION

In recent years, deregulation of electricity has emerged for its huge demand. Due to the deregulation of the electricity market, study regarding this matter has become imperative. Various initiatives are taken to overcome that, but utilization of FACTS device attracts everyone’s attention. FACTS devices are being played vital role for better utilization of the existing power system with the increased demaned [1], [2].

On the other hand, transmision and distribution orientation has become more severe due to the lack of proper arrangement. The major power loss occurs for system loss which is increasing day by day around the world and has emerged as a challange for the developing countries to run with limited resources. To minimise this transmission power losses and ensure optimal power flow, FACTS is introduced in power system. Different parameters and variables of the transmission line such as line impedance, terminal voltages and voltage angle can be controlled by FACTS devices in a fast and effective way [3].

Various types of FACTS devices such as Thyristor Controlled Series Compensations (TCSC), Thyristor controlled phase angle Regulators (TCPR), Unified Power Flow Controllers (UPFC) and Static Var Compensator (SVC) etc, are used to control the power flow in the network. These increase the flow in heavily loaded lines, there by resulting in increase load ability, lowering system losses, improved stability of network and reduced cost of production [4]. Although FACTS device has an great impact on power system for optimal power flow, but it requires optimal alocation for proper stabiliztion and localization. For that reason, many researches were made on the optimal location of FACTS devices with many different ways. We use GA technique to search the optimal localization of FACTS devices.

Genetic algorithms (GA) is a parallel and global search technique [5], [6], which generate solutions to optimization problems using natural evolution, such as inheritance, mutation, selection, and crossover. It is more likely to use for converging toward the global solution because it evaluates many points in the parameter space simultaneously. GA differs from other optimization and search procedures in four ways [7], such as (i) it can easily handle the integer or discrete variables because of coding of the parameter set, not the parameters themselves, (ii) it searches within a population of points, not a single point which may provide a globally optimal solution, (iii) it can deal with the non-smooth, non-continuous and no differentiable functions which are actually exist in a practical optimization problem, because it utilizes only objective function information, not derivatives or other auxiliary knowledge, (4) it uses probabilistic transition rules, not deterministic rules. Although GA seems to be a good method to solve optimization problem, but sometimes the solution obtained from GAs is only a near global optimum solution.

In this paper general GA is applied to improve stability, voltage profile of power system as well as to reduce transmission and generation losses using three types of FACTS devices. In [1], locatioin of FACTS devices are found on the basis of two parameters - overload and over voltage while in [11], only instalation and generation costs are considered. Our optimization includes all of above parameters. Moreover, reduction of generation cost**,** transmission losses, improved loadability and system stability were considered in the objective function of the GA for better improvement of the power system which are not considered altogether by previous work. IEEE 30 and IEEE 118 bus of power system are used for simulations.

The rest of the papers are organized as follows. Section II describes about optimal power flow where subsections A and B analyzes about optimization and analysis respectively. FACTS devices are described in section III where generalities & choice and modeling are explored in subsections A & B accordingly.

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We described about GA in section IV. Results are optimized in section V. Finally we conclude the work in section VI.

II. Optimal Power Flow

A. Power Flow Optimization

Optimal power flow (OPF) is a nonlinear programming problem which is also called load flow analysis, is very

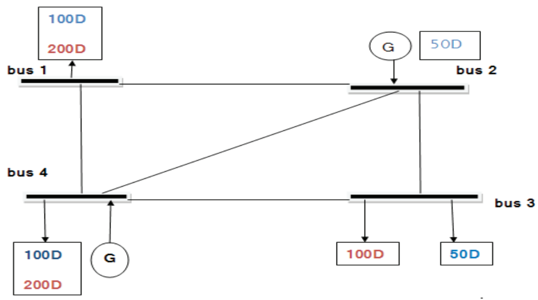


Figure 1. Configuration of 4-bus power system.

important for analysis of an electrical system. By analysis this the characteristics of the power flow direction in different line and the voltage at different buses can be easily obtain [8]. Fig. 1 shows an example of configuration of 4-bus power system where two bus has alternator to generate power and all bus share this power with different demand.Where red and blue indicate peak and off peak demand respectively. Due to increase in sudden load some buses are overloaded and some are with lag of load which causes difference in bus voltages and power flow in transmission line. So we need to calculate overall generation of power, cost, transmission loss, voltage stability in that time in an economic way. For that reasson power flow analysis is necessary.

B. Optimal Power Flow Analysis

The line resistance is small compared to the reactance and transverse capacitance is close to zero for intereconected power system network that obyes the Kirchoffs law. we consider only line reactances for interconection between i and j bus which is shown in Fig. 2. P_{ij} is the real power flow and Q_{ij} is the reactive power flow between two buses by a line is related by the following equations:

$$P_{ij} = \frac{V_i V_j}{X_{ij}} \sin\theta_{ij}, \tag{1}$$

$$Q_{ij} = \frac{1}{X_{ij}}\left(V_i^2 - V_i V_j \cos\theta_{ij}\right), \tag{2}$$

Where, V_i and V_j voltages at buses i and j respectively, X_{ij} reactance of the line, θ_{ij} angle between V_i and V_j. Here X_{ij} & θ_{ij} controls real and reactive power. We analyze these by Matlab power simulation package Matpower 4.1 [9].

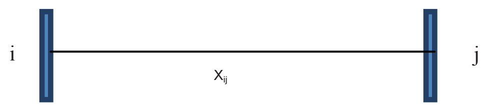


Figure 2. Bus i and bus j is conected by line with reactance Xij.

III. FACTS Devices

A. Introduce with FACTS Devices

The FACTS is power electronics based device which is used for AC power transmission and distribution. Due to rapid response, ability for frequent variations and smooth adjustability with output the applications of FACTS devices are increased day by day [10].

Different types of FACTS devices are used for power transmission and distribution such as SVC (Static Var Compensators), Fixed Series Capacitors (SC), Thyristor-Controlled Series Compensator (TCSC), Thyristor Controlled Phase Angle Regulator (TCPAR), Unified Power Flow Controller (UPFC), STATCOM etc. Power quality, availability, system stability, transmission capability can be improved using FACTS as well as it minimizes transmission and distribution losses. Here just TCSC,TCPAR and SVC are used for the optimal power flow analysis.

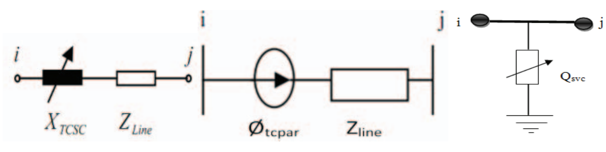
B. Choice and Modeling

Three different types of FACTS devices have been chosen for the controlling of power flow. These are TCSC, TCPAR, and SVC. TCSC is used to modify the reactance of the transmission line X_{ij}. For controlling the phase angle θ_{ij} the TCPAR is used. The SVC is used to absorb or inject reactive power which is connected in shunt with the line. Both the TCSC and TCPAR are connected in series with the line.

Each FACTS device is represented with fixed discrete values for mathematical analysis, where it has two possible characteristics, capacitive or inductive accordingly in order to decrease or increase the line reactance, phase angle, reactive power in line using TCSC, TCPAR and SVC respectively. Maximum and minimum value of each FACTS device is fixed and type of each device is also specified. TABLE I represents the specification of FACTS devices. Fig. 3 shows the connection model of FACTS devices.

TABLE I. SPECIFICATION OF FACTS DEVICES

Name/Specification	***TCSC***	***TCPAR***	***SVC***
Device type	1	2	3
Minimum value	-0.8 X_L (Capacitive)	- 5 deg.	-100 MVar
Maximum value	0.2 XL (Inductive)	+5 deg.	+100 MVar



(a) (b) (c)

Figure 3. Connection models of FACTS devices. (a) TCSC (b) TCPAR (c) SVC

The real value of the FACTS device [1] V_{realF} is calculated with there loccation according to the model of the FACTS by

$$V_{realF} = V_{\min F} + (V_{\max F} - V_{\min F})V_F \tag{3}$$

Where, the normalized value is V_F, the maximum and minimum setting value are V_{maxF} and V_{minF} respectively.

IV. Genetic Algorithm

A. GA overview

GA was proposed on the basis of the evolutionary ideas of natural selection and genetics [5], [6]. It represents an intelligent exploitation of a random search used to solve optimization problems which is a rapidly growing area of artificial intelligence (AI). Because of independent of the choice of the initial configurations GA finds high quality solutions. Moreover, they are computationally simple and easy to implement. Genetic diversity or variation is configured using different operators such as reproduction (selection), crossover (recombination) and mutation.

B. Model of GA

The main objective of the optimization is to find the best location for a given number of FACTS devices in the power system based on defined criterion. Three parameters are utilized for encoding individual these are the location, type of device and rated value [1], [12]. Each individual is represented by *nF* number of three strings, where *nF* is the number of FACTS devices installed in the power system. TABLE II shows the individual format. Individual is made in three stages, first a set of branches are randomly selected and is put in the first string. In the second string type is also randomly selected. In the third string device setting value is randomly selected. This approach is repeated for obtaining desired population. Then the entire population is computed with respect to objective function which is the measure of obtaining best location for the FACTS device.

TABLE II. Individual Format For GA

Location	*FACTS Type*	*Normalized value*
2	1	0.3
5	3	0.6
11	1	0.2
22	2	0.9
26	1	0.5
18	3	0.1

New individual is generated based on the results obtained from the old generation. For this 1st GA operator selection is used. In this case Proportional Roulette Wheel Selection technique is used. In proportional roulette wheel, individuals are selected with a probability that is directly proportional to their fitness values i.e. an individual selection corresponds to a portion of a roulette wheel. Let F_i be the fitness value and P_i be the selection probability, then

$$P_i = \frac{F_i}{\sum_{i=1}^{N} F_i} \tag{4}$$

Based on the selection probability P_i individual is randomly selected by roulette wheel. After that 2nd GA uniform crossover is applied [5]. Uniform crossover with some probability knows as the mixing ratio. The crossover operator allows the parent chromosomes to be mixed at the gene level. Consider the two parents selected for crossover. If the mixing ratio is about 0.5, then half of the genes in the offspring will come from parent 1 and rest from parent 2. Then boundary mutation is applied. Fig.4. shows the uniform crossover and boundary mutation technique clearly. Crossover and mutation is done after selection of parents. Blue and black colors represent parent 1 and parent 2 respectively. Then we obtain offspring according to crossover of parents and mutation. The red color shows the mutation results where other for crossover.

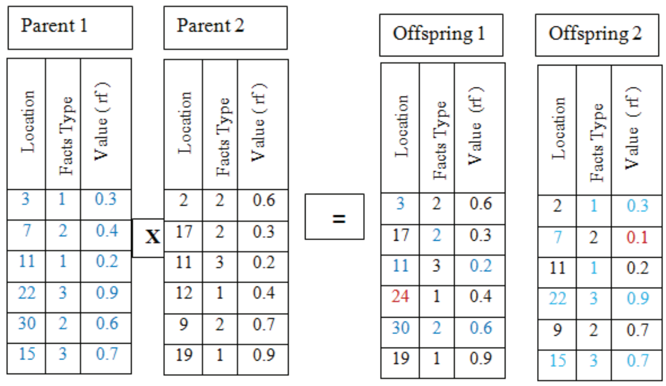


Figure 4. Crossover and Mutation approach.

The entire methodology of GA is explained in Fig. 5. Firstly individuals are selected randomly. Then fitness value is calculated for each individual based on the fitness function. Best individual is found according to selection, crossover and mutation when final criterion is reached.

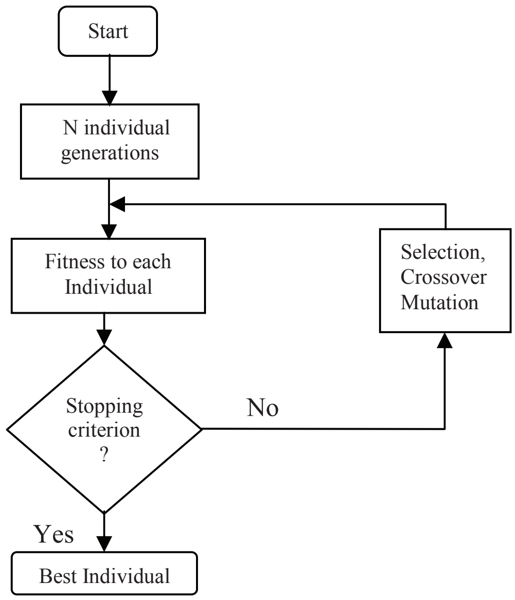


Figure 5. Flow chart of the optimization strategy.

V. Optimization and Result

A. Objective function

The aim of the optimization is to find the best locations for the given number of FACTS devices within the defined constrains for the best utilization of the existing system. We want to minimize the power generation costs and reduce the transmission and distribution losses. So the objective function is based on the minimization of cost which can be expressed as

$$C_{Total} = C_1(f) + C_2(PG) + C_3(PL)\,, \tag{5}$$

Where, C_{Total}, C_1 (f), C_2 (PG), C_3 (PL) are the total cost of objective function, average installation costs of FACTS devices at each observation per hour, total generation costs and cost of power transmission losses respectively.

The cost functions for SVC, TCSC and TCPAR are developed on the basis of the Siemens AG Database [8], [15]

The cost function for SVC and TCSC are:

$$C_{svc} = 0.0003S^2 - 0.3051S + 127.38(US\$/K\text{var}) \tag{6}$$

$$C_{t\,\text{csc}} = 0.001S^2 - 0.713S + 153.75(US\$/K\text{var}) \tag{7}$$

Where S is the operating range of the FACTS controllers in kVar. Depending on the installment cost, the cost function of TCPAR can be expresed as

$$C_{tcpar} = 140.5(US\$/K\text{var}) \tag{8}$$

The cost function for SVC, TCSC and UPFC from Siemens AG Database is shown in Fig. 6.

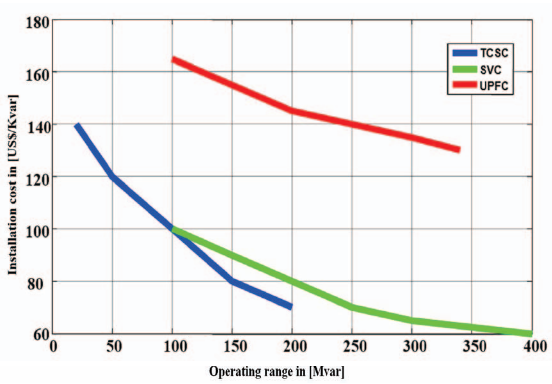


Figure 6. Installation cost curve

Now if C(f) is the summetion of the used FACTS device instalation cost. The generation cost is calculated in per unit that is *US$/Hour* and the installation costs of FACTS devices are in *US$*. For that reason life time of the FACTS is considered. In this paper, three years is applied to evaluate the cost function [10], [11]. We calculate the average values of the installation costs using the following equation, where 8760 is the total hour in a year.

$$C_1(f) = \frac{C(f)}{8760 \times 3}(US\$/Hour) \tag{9}$$

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

$$C_2(PG) = \alpha_0 + \alpha_1 PG + \alpha_2 (PG)^2 \tag{10}$$

Where PG is the output of the generator (MW), and α0, α1 and α2 are cost coefficients.

The cost function for power loss is represented as

$$C_3(PL) = \sum_{i=1}^{N} PL * Eloss * dt \tag{11}$$

Where, N, P*L,* Eloss and dt are denotes the number of used FACTS devices, transmissin losses, cost of the losses in per hour and FACTS devices utilization time respectively.

Now the fitness function for the genetic algorithm is found as

$$\text{Fitness} = 1/C_{\text{Total}} \tag{12}$$

B. Results

According to variation of fitness function individuals are generated using GA to optimize the power flow. The simulation is carried out by free Matlab power simulation package Matpower 4.1 [9]. Based on the GA, best fittest individual is found for the optimal power flow in IEEE 30 and IEEE 118 bus power system with increased amount of demand. Reduction of the power loss and improvement of the voltage profile during transmission are introduced here those are shown in Figs. 9 and 10 accordingly.

Figs.7 and 8 show the fitness value of the fitness function with respect to generation for IEEE 30 and IEEE 118 bus power system respectively.

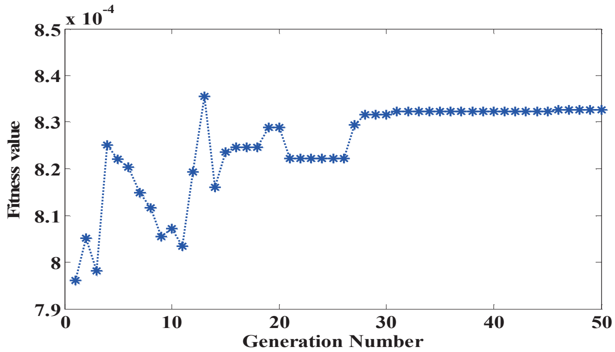


Figure 7. Fitness function curve with generation for IEEE 30 bus system

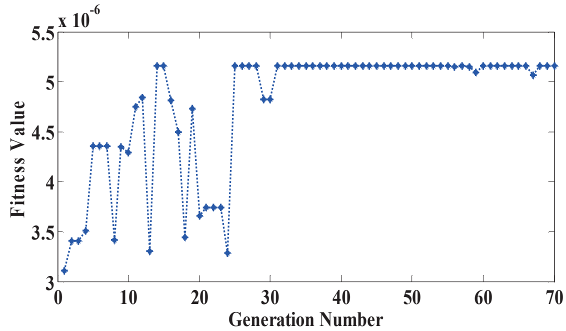
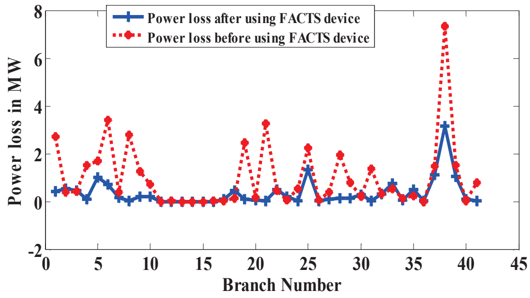
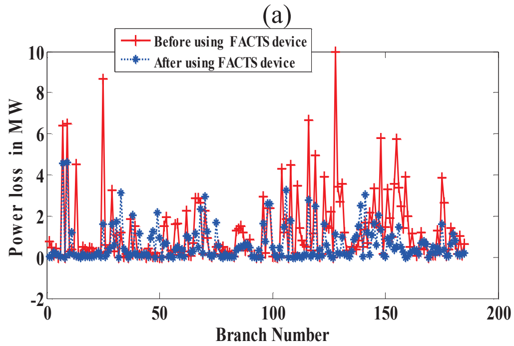


Figure 8. Fitness function curve with generation for IEEE 118 bus system.

Fig. 9 shows both for the IEEE 30 bus and IEEE 118 bus that before using FACTS device power loss through line is more which is showed with red mark. After using FACTS device power loss through line reduced and it is showed by blue mark. Although in some case little increasement of power loss after using FACTS device but it is negligible. So overall performance is much better after using FACTS device. It has found that obtained location is showing satisfactory output.



(a)

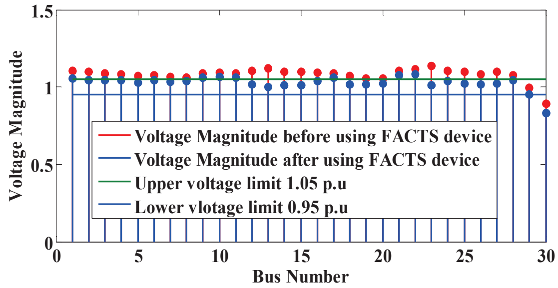


(b)

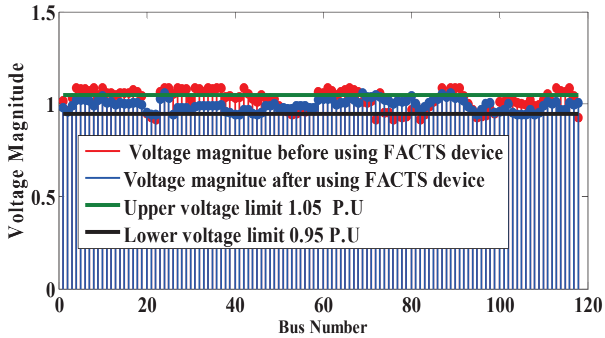
Figure 9. Comparison of power loss before and after using FACTS device in (a) IEEE 30 bus (b) IEE118 bus.

Fig. 10 shows both for IEEE 30 and IEEE 118 bus it is found that voltage magnitude (VM) profile is better while using FACTS device than without FACTS device. As voltage magnitue sholud stay in the limit 1.05 and 0.95 per unit which is marked by color green and black, without FACTS device VM is marked by red color which is very poor. On the other hand after FACTS device utilization voltage profile is marked by blue and it is more stable.

Optimal locations in the power system are detected by using genetic algorithm for the FACTS device. At the same time specifed FACTS device with specifed value which is highly effective for optimal power flow is too determined. After applying these obtainted outcome in the power system, final optimal power flow is observed in the IEEE 30 and IEEE118 bus system. In the IEEE 30 and IEEE118 bus system it was observed that transmission loss reduced in the system after iinstalling FACTS device during certain increase in the load in the system. It was also too observed that voltage profile at each bus of the system improved after installing FACTS device.



(a)



(b)

Figure 10. Voltage Magnitude profile comparision before and after using FACTS device in (a) IEEE 30 bus (b) IEEE118 bus

VI. Conclusion

A genetic algorithm has been presented with larger parameters than previous methods to optimally locate FACTS devices in the power system. Here only three types of FACTS devices are used and simulation is carried out on IEEE 30 bus and IEEE 118 bus. After simulation FACTS devices are used in the obtained location and the power flow of the system is observed. It is found that power transmission loss has reduced for using FACTS devices in case of IEEE 30 bus for 90% cases and in case of IEEE 118 it is about 75%. So transmission losses are reduced. In case of bus voltage profile, about 95% bus voltage remain within the limit due to use of FACTS device in IEEE 30 bus and in case of IEEE 118 bus it is about 80%. So it can be said that overall FACTS device has a great impact in power system for optimal power flow and in that case Genetic algorithm exhibits a great impact for selecting the perfect location.

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