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FUZZY – GENETIC ALGORITHM APPROACH FOR FACT PLACEMENT IN ELECTRICAL POWER SYSTEM

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ABSTRACT

This paper presents an approach of hybrid methods for facts placements in electrical system using fuzzy logic and genetic algorithm. The conventional of FACT placement is improved for decision making over a distributed power system with the learning efficiently of genetic algorithm and decision making of fuzzy logic. The method proposed is evaluated with conventional Thyristor Control Series Compensator (TCSC) method over variable MVAR rating for evaluation of cost function under different electrical ratings.

Keywords: *upfc, tcsc, fuzzy logic, genetic algorithm, hybrid method.*

I. INTRODUCTION

These days, the importance of a power system design and operation with high efficiency, maximum reliability and security has to be considered more than ever. Some difficulties, such as right of way and transmission line expansion, force the use of the maximum capacity of transmission lines and, therefore, providing voltage stability, even under normal conditions, become more difficult. This problem is serious, due to the fact that the main duty of generation units is based on active power generation rather than reactive power compensation. Flexible AC Transmission Systems (FACTS) devices, as modern compensators of active and, reactive powers, can be considered viable options in providing voltage security constraints and their feasibility in power systems, simultaneously, because of their fast responses against perturbations in urgent circumstances, flexible performance under normal conditions and their ability to be used in dynamic situations. Note that it is also possible to consider the global voltage stability indicator in FACTS devices allocation problems. In order to allocate the FACTS devices according to their characteristics, various objectives have been considered. For instance, static voltage stability enhancement [1-4], violation diminution of the line thermal constraints [5], network load-ability enhancement [6,7], power loss reduction [8], voltage profile improvement [6] and the fuel cost reduction of power plants using optimal power below [9] are some objectives for tasks reported in the literature. Furthermore, to approach these objectives, some simplifications, such as using single objective optimization, neglecting the investment budget as a part of the objective function, and allocation, based on decoupled active and reactive components in the presence of a multi-objective function [9], have been made. These assumptions cause some problems such as, an inability to use the powerful advantages of FACTS devices, impractical allocation results and inaccurate solutions of the problem. It is noted that each of the mentioned objective improves the power system network operation and approaching them is the aim of all power system networks. It is obvious that minimum power loss leads to the optimum operation of power system lines. Therefore, none of the mentioned objectives can be neglected for FACTS devices allocation. On the other hand, the allocation of unlimited FACTS devices, according to one or more objectives, without considering the cost of devices cannot be justified [6].

The paper focus on improving previous research in the field of FACTS devices allocation in power systems. That means, static voltage stability enhancement, network load ability enhancement, power loss reduction and voltage profile improvement are considered as allocation objectives, and the reduction of power loss and FACTS devices investment costs are also considered in the objective function. Note that the alleviation of both cost factors is taken into account in the allocation problem. Despite previous work and in an effort to approach a practical solution, an estimated annual load profile has been considered to calculate power loss and voltage violation. The FACTS devices are assumed to be the Thyristor Controlled Series Compensator (TCSC) and the Static Var Compensator (SVC) in this study. Therefore, the logical solution of allocation is to satisfy the mentioned objectives in a multi-objective optimization. One of the necessities of a multi-objective optimization problem is providing a scheme that can simultaneously translate all the objectives into a single optimization problem. The optimization problem needs to have the ability to take all the predetermined objective values by the designer. In this paper, an approach based on a fuzzy evaluation technique [10], combined with a genetic algorithm, is used to compromise between contradictory objectives. Also, in order to implement an estimated annual load profile to accurately find the optimum location and capacity of FACTS devices, a Sequential Quadratic Programming (SQP) optimization sub-problem has been used as part of an overall optimization procedure.

This paper is organized as follows: First the mathematical concept of multi-objective allocation is presented, and the models of TCSC and SVC are described that have been used for static security enhancement. Then, a fuzzy evaluation technique into GA, to replace the fitness function for constituting a multi-objective optimal model and implemented optimization procedure, has been described. After that, the results of the proposed method, on the IEEE 14-Bus test system and the Fars regional electric network, are presented and analyzed. The locations and amounts of the nominated devices that satisfy the mentioned objectives are also determined and finally, the conclusion of the paper is presented.

II. FACTS MODELS

A. FACTS Devices

Four FACTS devices have been selected for the usage of implementation namely TCSC (Thyristor Controlled Series Capacitor), TCPST (Thyristor Controlled Phase Shifting Transformer), UPFC (Unified Power Flow Controller), and SVC (Static Var Compensator). The reactance of the line can be changed by TCSC. TCPST varies the phase angle between the two terminal voltages and SVC can be used to control the reactive compensation. The UPFC is the most powerful and versatile FACTS device due to the facts that the line impedance, terminal voltages, and the voltage angle can be controlled by it as well.

For an electrical system the power flow P_{ij} through the transmission line *i-j* is a function of line impedance X_{ij}, the voltage magnitude $V_i\,,V_j$ and the phase angle between the sending and receiving end voltages $\delta_i - \delta_j$.

$$P_{ij} = [(V_i V_j) / X_{ij}] * (\delta_i - \delta_j)$$

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. Moreover, in a multi-machine network according to the different utilization of generation units in case of FACTS, the generation costs can also be reduced.

B. Mathematical Modeling

The mathematical models of the FACTS devices are developed to perform the steady-state operation. Therefore the TCSC is modeled to modify the reactance of the transmission directly. The SVC, TCPST and UPFC are modeled using the power injection method [4]. Furthermore, for the TCSC, TCPST and UPFC, their mathematical model is integrated into the model of the transmission line. Whereas the SVC model is only incorporated into the sending end as a shunt element of the transmission line. The mathematical models of FACT is as shown in Fig. 1,

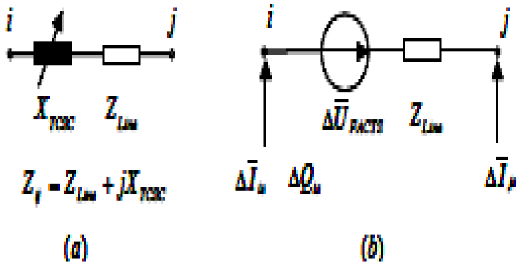


Fig. 1. Mathematical models of the FACTS devices.
(a) TCSC. (b) TCPST, UPFC and SVC.

The TCSC can serve as the capacitive or inductive compensation respectively by modifying the reactance of the transmission line. In this simulation, 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:

$$X_{ij} = X_{Line} + X_{TCSC}, \quad X_{TCSC} = rtcsc \cdot X_{Line}$$

where X_{Line} is the reactance of the transmission line and *rtcsc* is the coefficient which represents the compensation degree of TCSC. To avoid overcompensation, the working range of the TCSC is between –0.7X_{Line} and 0.2 X_{Line} [1,2].

$$rtcsc_{min} = -0.7, \quad rtcsc_{max} = 0.2$$

The voltage angle between the sending and receiving end of the transmission line can be regulated by TCPST. It is modeled as a series compensation voltage $\Delta U_{FACTS} = \Delta U_{TCPST.}$ The voltage angle between the sending and receiving end of the transmission line can be regulated by TCPST. It is modeled as a series compensation voltage $\Delta U_{FACTS} = \Delta U_{TCPST}$ as shown in Fig 1.(b), which is perpendicular to the bus voltage. The working range of the TCPST is between –5 degrees to +5 degrees. The injected currents at bus *i* and bus *j* is expressed as:

$$\Delta \bar{I}_{is} = \frac{\Delta \bar{U}_{TCPST}}{Z_{ij}}, \quad \Delta \bar{I}_{js} = -\frac{\Delta \bar{U}_{TCPST}}{Z_{ij}}$$

The SVC can be operated at both inductive and capacitive compensation. It is modeled as an ideal reactive power injection at at bus *i*, as shown in Fig. 1 (b). The injected power at bus *i* is:

$$\Delta Q_{is} = Q_{SVC}$$

Basically, the UPFC has two voltage source inverters (VSI) sharing a common dc storage capacitor. It is connected to the system through two coupling transformers [6,7,12]. In this simulation, the series compensation $\Delta U_{FACTS} = \Delta U_{UPFC}$ is employed. The injected currents at bus *i* and bus *j* can be expressed as follows:

$$\Delta \bar{I}_{is} = \frac{\Delta \bar{U}_{UPFC}}{Z_{ij}}, \quad \Delta \bar{I}_{js} = -\frac{\Delta \bar{U}_{UPFC}}{Z_{ij}}$$

III. COST FUNCTIONS

As mentioned above, the main objective of this paper is to find the optimal locations of FACTS devices to minimize the overall cost function consisting of generation costs and FACTS devices investment costs. For minimizing the generation costs in power systems, algorithms are well developed and being used for unit commitment and operation. The cost functions incorporated for GA modeling are:

- Generation costs.
- Investment costs of FACTS devices.

A) Generation cost function

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

$$c_2(P_G) = \alpha_0 + \alpha_1 P_G + \alpha_2 P_G^2$$

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

B) FACTS devices cost functions

Based on the Siemens AG Database [8], the cost functions for SVC, TCSC and UPFC are developed: The cost function for UPFC is:

$$c_{1UPFC} = 0.0003s^2 - 0.2691s + 188.22(US\$/kVar)$$

For TCSC:

$$c_{1TCSC} = 0.0015s^2 - 0.7130s + 153.75(US\$/kVar)$$

For SVC:

$$c_{1SVC} = 0.0003s^2 - 0.3051s + 127.38(US\$/kVar)$$

where $c1_{UPFC}$, $c1_{TCSC}$ and $c1_{SVC}$ are in *US$/kVar* and '*s*' is the operating range of the FACTS devices in M_{Var}. The cost of a TCPST is more related to the operating voltage and the current rating of the circuit concerned [2,3,5]. Thus, once the TCPST is installed, the cost is fixed and the cost function can be expressed as follows [5]:

$$C_{TCPST} = d \cdot P_{max} + IC$$

where *d* is a positive constant representing the capital cost and *IC* is the installation costs of the TCPST respectively. P_{max} is the thermal limit of the transmission line where TCPST is installed [5]. For the optimization of the FACT placement Genetic algorithm were used. The GA approach is outlined in following section.

IV. GENETIC ALGORITHMS

Based on the mechanisms of natural selection and genetics, GAs (genetic algorithms) are global search techniques. They can search several possible solutions simultaneously and they do not require any prior knowledge or special properties of the objective function [1,11]. Moreover, they always produce high quality solutions and, therefore, they are excellent methods for searching optimal solution in a complex problem. The GAs start with random generation of initial population and then the selection, crossover and mutation are proceeded until the best population is found. Particularly, GAs are practical algorithm and easy to be implemented in the power system analysis.

A). Encoding

The objective is to find the optimal locations for the FACTS devices within the equality and inequality constrains. Therefore, the configuration of FACTS devices is encoded by three parameters: the location, type and its rated value [1]. Each individual is represented by *FACTS n* number of strings, where *FACTS n* is the number of FACTS devices needed to be analyzed in the power system, as shown in Fig. 2.

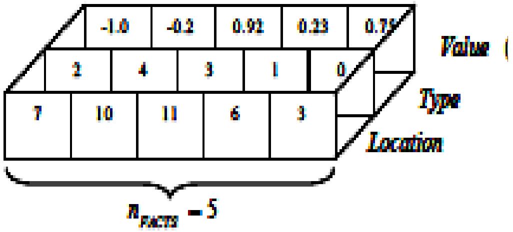


Fig. 2. Individual configuration of FACTS devices.

The first value of each string corresponds to the location information. It is the number of the transmission line where the FACTS is to be located. Each string has a different value of location [1]. In other words, it must be ensured that on one transmission line there is only one FACTS device. Moreover, SVC is installed only at one node of the transmission line and the sending node is selected in this simulation.

The second value represents the types of FACTS devices [1]. The values assigned to FACTS devices are: 1 for TCSC; 2 for TCPST; 3 for UPFC, 4 for SVC and 0 for no FACTS situation. Particularly, if there is no FACTS device needed on the transmission line, the value 0 will be employed. The last value *rf* represents the rated value of each FACTS device. This value varies continually between –1 and +1. The real value of each FACTS device is then converted according to the different FACTS model under the following criterion:

TCSC: TCSC has a working range between $-0.7X_{Line}$ and $0.2X_{Line}$ [2,3], where X_{Line} is the reactance of the transmission line where the TCSC installed. Therefore *rf* is converted into the real compensation degree *rtcsc* using the following equation:

$$rtcsc = rf \times 0.45 - 0.25$$

UPFC: The inserted voltage of UPFC has a maximum magnitude of m x 0.1 V, where m V is the rated voltage of the transmission line where the UPFC is installed. The angle of *UUPFC* can be varied from −180° to 180°. Therefore *rf* is converted into the working angle *rupfc* using the following equation:

$$rupfc = rf \times 180\ (degrees)$$

TCPST: The working range of TCPST is between − 5° and 5° . Then *rf* is converted into the real phase shift value *rtcpst* using the following equation:

$$rtcpst = rf \times 5\ (degrees)$$

SVC: The working range of SVC is between –100Mvar and 100MVar. Then *rf* is converted into the real compensation value using:

$$rsvc = rf \times 100\ (MVar)$$

B. Initial Population

The initial population is generated from the following parameters [1]:

FACTS n : the number of FACTS devices to be located. *Type n* : FACTS types.

Location n : the possible locations for FACTS devices.

Ind n : the number of individuals of the population. First, as shown in Fig. 3, a set of *FACTS n* numbers of strings are produced. For each string, the first value is randomly chosen from the possible locations *Location n* . The second value, which represents the types of FACTS devices, is obtained by randomly drawing numbers among the selected devices [1]. Particularly, after the optimization, if there is no FACTS device necessary for this transmission line, the second value will be set zero.

The third value of each string, which contains the rated values of the FACTS devices, are randomly selected between –1 and +1. To obtain the entire initial population, the above operations are repeated *Ind n* times [1]. Fig. 3 shows the calculation of the entire population.

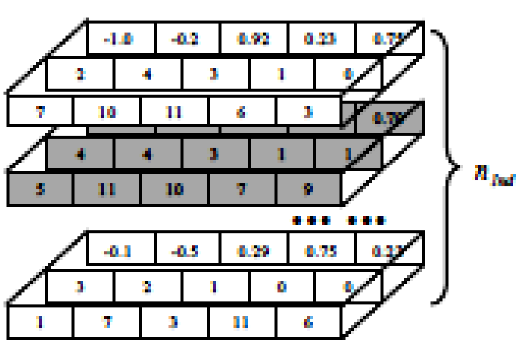


Fig 3: calculation of the entire population

C. Fitness Calculation

After encoding, the objective function (fitness) will be evaluated for each individual of the population. The fitness is a measure of quality, which is used to compare different solutions [1, 11]. In this work, the fitness is defined as follows:

$$Fitness = m - c_{Total}$$

Because the GAs can only find the maximum positive value of the objective function, a large positive constant *m* is selected to convert the objective function into a maximum one.

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

D. 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 [1] is employed. The probability of an individual's reproduction is proportional to its part on the biased roulette wheel [11].

E. Crossover

The main objective of crossover is to reorganize the information of two different individuals and produce a new one [1, 11]. A two-point crossover [1] is applied and the probability *pc* of the crossover is selected as 0.95. First, two crossing points are selected uniformly at random along the individuals. Elements outside these two points are kept to be part of the offspring. Then, from the first position of crossover to the second one, elements of the three strings of both parents are exchanged [1, 11].

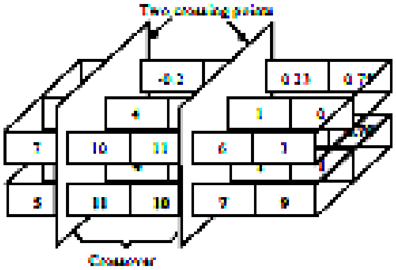


Fig 4: Two points crossover

F. Mutation

Mutation is used to introduce some sort of artificial diversification in the population to avoid premature convergence to local optimum [4, 11]. Non-uniform mutation, which has proved to be successful in a number of studies [11], is employed in this paper.

For a given parent $l\ X = x_1\ x_2\ x_3 \ldots\ X_k \ldots x_l$, if the gene x_k is selected for mutation and the range of x_k is $[u^k_{min}, u^k_{max}]$ then the result x'_k is

$$x'_k = \begin{cases} x_k + \Delta(t, U^k_{Max} - x_k) & if \quad random(0,1) = 0 \\ x_k - \Delta(t, x_k - U^k_{Min}) & if \quad random(0,1) = 1 \end{cases}$$

where

$$\Delta(t,y) = y \cdot \left(1 - r^{\left(1-\frac{t}{T}\right)^b}\right)$$

$\Delta(t, y)$ (y represents $x_k - u^k_{minn}$ and $u^k_{mix} - x_k$) returns a value in the range $[0,y]$. Its probability being close to 0 and increases as t increases (t is generation number). This property enables the operator to search the space uniformly initially (when t is small), and very locally at later stages [11]. In (19), r is a random value in the range of $[0,1]$ and b is a parameter determining the degree of non-uniformity. In this simulation, b=2 is applied. The above-mentioned operations of selection, crossover and mutation are repeated until the best individual is found.

The proposed optimization strategy is summarized in Fig. 5.

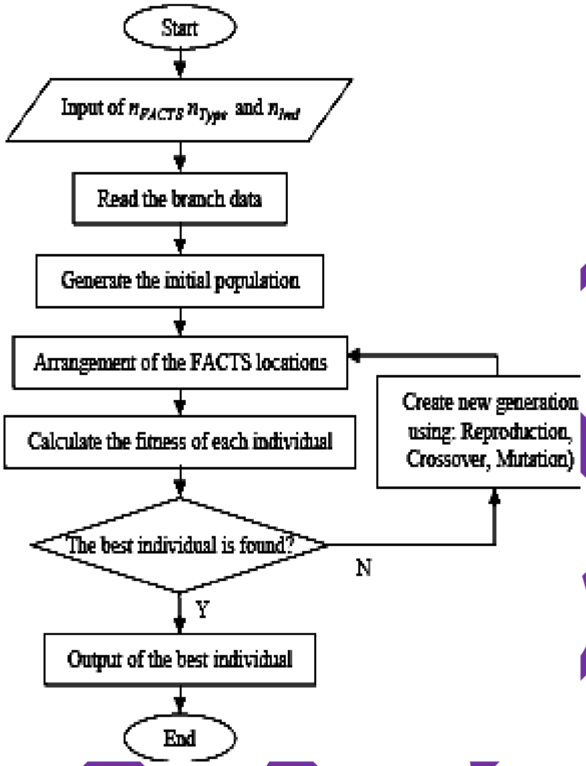


Fig.5. Flow Chart of the GA optimization

In order to ensure that there is only one FACTS device on each transmission line, the process of Arrangement of the FACTS locations' is necessary.

V. RESULT OBSERVATION

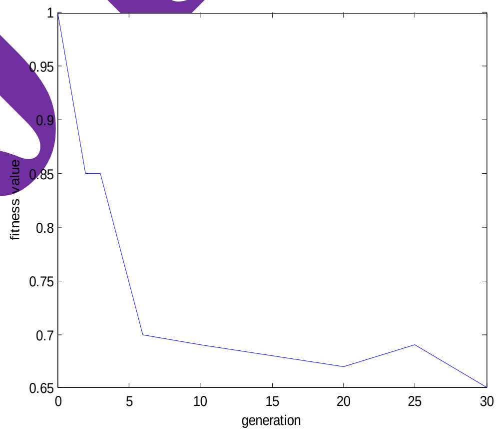


Fig 6. As can be seen in the figure which shows the evaluation of fitness function during GA optimization observation shows that the fitness value gets stabilizes at certain point after it is dropped to a limit.

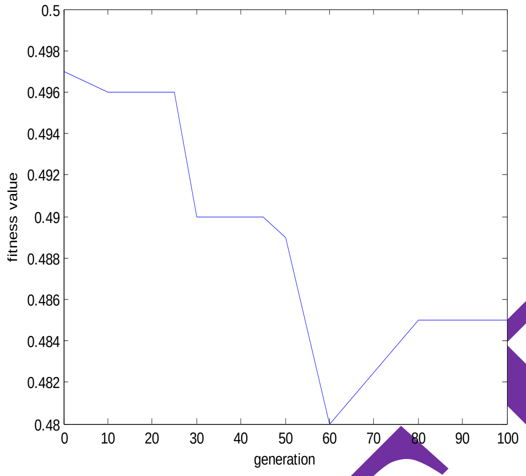
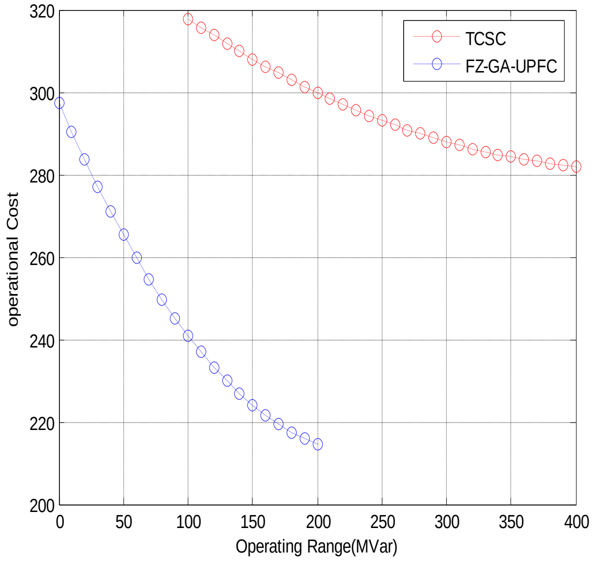
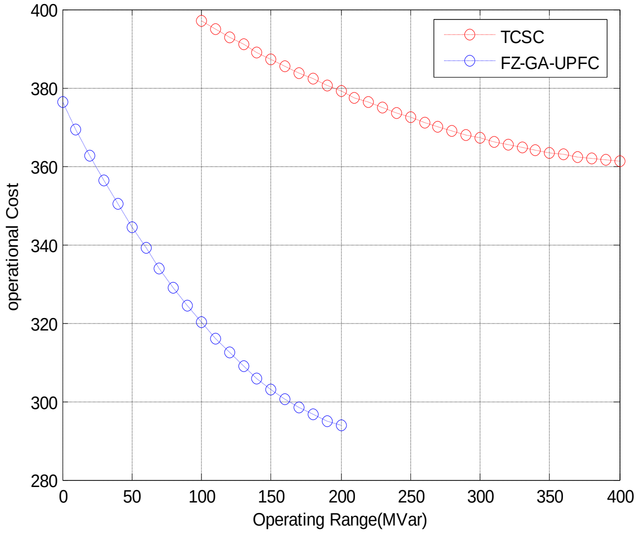


Fig 7. Fitness function evaluation during GA optimization represented in the graphs where fitness values can be observed is stabilized after certain generation.

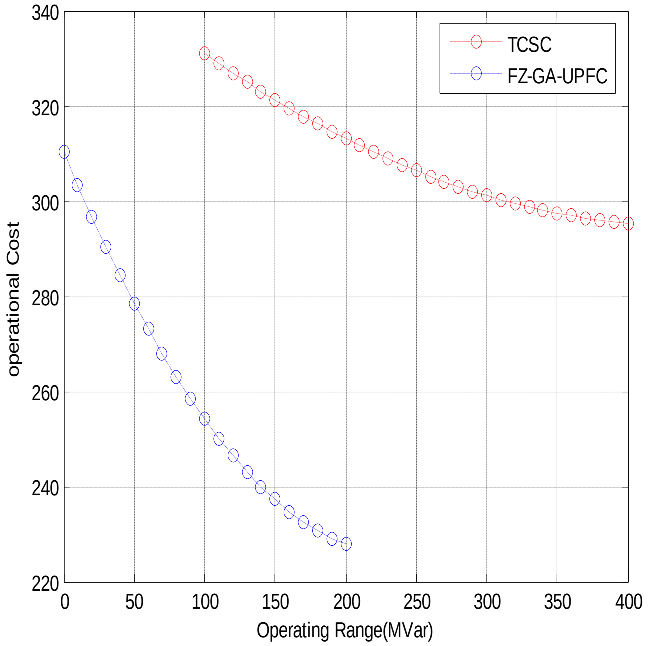
z1=0.75; %%%% Line Impedence
mva=180;
vL=41.2;



z1=0.45; %%%% Line Impedence
mva=120;
vL=21.2;



z1=0.95; %%%% Line Impedence
mva=220;
vL=61.2;



VI. CONCLUSIONS

This paper presents a hybrid approach for fact placement in distributed electrical system based on the incorporation of genetic algorithm and fuzzy logic. It is observed that suggested UPFC based technique is comparatively better performing in cost evaluation than the conventional TCSC method. The variation over different range of MVAR reduces the usage cost with increase in required operating range.

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