OPTIMAL LOCATION OF THYRISTOR CONTROLLED SERIES COMPENSATOR (TCSC) FOR ENHANCING POWER SYSTEM LOADABILITY USING GENETIC ALGORITHM.

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ABSTRACT: This paper presents heuristic method, genetic algorithm to find optimal location of FACTS device in power system. The loadability limit of the system is found by observing constraints like bus voltage, line loading and voltage angle while doing incremental changes in generation and load. As Thyristor Controlled Series Compensator (TCSC) is having good capabilities for enhancement of loadability, TCSC is introduced, when any of constraints is violated. The performance of TCSC is verified for each branch except branch containing tap-changing transformer. The loadability is found for the system without TCSC and after introducing TCSC in every branch (one line at a time). The objective function is to maximize system loadability by maintaining the non-violation of constraints.
Key Words: TCSC, Power system loadability, Genetic Algorithm, IEEE-14 bus system

I. INTRODUCTION

In the current scenario of power system, the load demand is increasing day by day. Due to de-regulated power system, the lines are operated near thermal limit [1]. Therefore, it is mandatory to search for options to overcome this scenario. This option may be anyone of followings: (1) Construct a new transmission line (2) Apply some topological changes into the existing system.It is never be feasible to go for first option. FACTS are having characteristic of doing some topological changes into the existing system. They enhance the system performance by re-dispatching the flow patterns and reducing the loop flows in such a way that the contractual requirement between grid and stockholders and increased load demands are satisfied [2]. The cost of FACTS devices is to be justified for a given system [3]. So, FACTS should be located optimally in a system. The methods for optimization the location of FACTS may be analytical method or heuristic method [1-11]. The objective for optimization may be loss minimization, cost minimization, enhancing voltage stability, power system security and may be enhancing power system loadability. Among all these aspects enhancing loadability is very important concept. Because, if there is any reserve capacity available, why the other alternatives should be searched like constructing new transmission line or establishing new generating station.This paper is organized as follows. The influence of FACTS device on power flow equation is discussed in section-II. In section-III steps to be followed with detailed process for Genetic Algorithm. In section-IV the result and discussion for IEEE-14 bus system is discussed and section-V concludes the paper.

II. FACTS DEVICES IN POWER FLOW

There are three types of FACTS devices: series device, shunt device and combined device. These FACTS are having different parameters to be controlled, which can be understood by power flow equations.

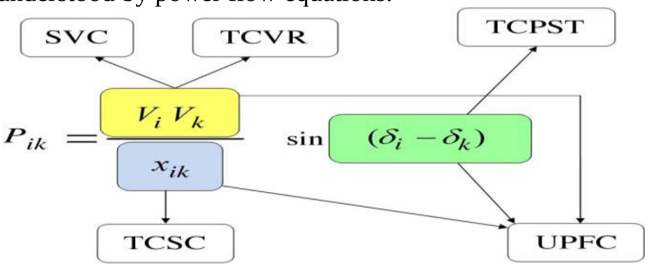


Fig.1. Impacts of FACTS devices on the variables involved in the active power flow equation [11].

The power flow equations can be written as:

$$P_{ik} = -P_{ki} = \frac{V_i V_k}{x_{ik}} \sin(\delta_i - \delta_k)$$

$$Q_{ik} = -Q_{ki} = \frac{1}{x_{ik}} [V_i^2 - V_i V_k \cos(\delta_i - \delta_k)]$$

where Vi and Vk are the voltage magnitudes of buses i and k, x_{ik} is the line reactance and δi-δk =δik is the difference angle between phasors Vi and Vk . In normal power system operation, δik is small and the voltage magnitudes are typically 1.0 p.u. We can therefore easily decouple the active and reactive power controls from each other. While the active power flow is influenced by δik and x_{ik}, the reactive power flow is related to the value of (Vi -Vk) and x_{ik}. Fig. 1 shows the active power flow equation between two buses i and k and it is the variables that can be controlled by each FACTS device.

To Study the effects of FACTS devices on power system, the modeling of FACTS devices is done. In available literature mathematical modeling of FACTS devices are done. Mathematical models for FACTS devices are implemented by MATLAB programming language. [1] In some papers other software like EUROSTAG™ software is used [3]. In other paper the modeling is done using MATPOWER, which is extension of MATLAB [1,11].

For a power system without FACTS devices, the power flow with normal power equations can be done using Newton-Raphson method. But, when FACTS devices are involved in power system for compensation and performance improvement, the modeling is done. i.e. when TCSC is used in power system, for analysis purpose it is modeled as variable reactance.

The TCSC may have one of the two possible characteristics: capacitive or inductive, respectively to decrease or increase the reactance of the line. It is modeled with three ideal switched elements in parallel: a capacitance, an inductance and a simple wire, which permits the TCSC to have the value zero. The capacitance and the inductance are variable and their values are function of the reactance of the line in which the device is located. In order to avoid resonance, only one of the three elements can be switched at a time. Moreover, to not over compensate the line, the maximum value of the capacitance is fixed at $-0.8X_L$.For the inductance, the maximum is $0.2X_L$ [1,12].

TCSC can be very efficient in enhancing loadability of power system. By changing reactance of TCSC, ultimately impedance of branch is changed in which TCSC is connected. The power flowing in that branch changes and due to this power flowing in other branches is re-dispatched.
In this paper TCSC is selected to enhance the loadability of power system. The software used is for power flow analysis is MATPOWER. As there are 20 numbers of branches in IEEE-14 bus system, the probable locations of TCSC may be all the branches excluding the branches in which tap-changing transformer is connected. In MATPOWER branches are model as pi-line. So, the parameter affected by selected FACTS devices are to be changed to run power flow analysis [11,12]. If TCSC is connected in any branch it will be treated as if a new bus is created and impedance of old line is transferred between newly created bus and one of the old bus [13].

III. ALGORITHM PROCESS

A. Genetic Algorithm

The genetic Algorithm is the stochastic method to find solution of both constrained and unconstrained problem based on natural selection mechanism. Population of individual solutions are repeatedly modified. Successive generations lead to optimal solution.
The process starts with creation of random initial population as shown in fig 2. There would be mutation and crossover operator applied as per the selected ratio and new generations are tested by their fitness. The elite children are passed to the next population, who are having best fitness value. Over successive generations, there will be optimal solution.

FACTS Location Value

1	5	0.025	String-1
1	6	0.017	String-2

Fig.2. Original Individuals

Mutation children are created by randomly changing the genes of single individual parent and the crossover children is created by combining two pair of parents.

B. Objective function of optimization process

The goal of this optimization is to maximize system loadability without violation of bus voltage and branch loading.
For this initial loading condition as load factor $\lambda=1$ is considered, which is thereafter to be increased with optimization process.
Generating power of the generators are modified as
$P_{Gi}= \lambda.P_{Goi}$.
For the load buses the P and Q are modified as
$P_{Li}= \lambda.P_{loi}$ and $Q_{Li}= \lambda.Q_{Loi}$
Where P_{loi} and Q_{Loi} are initial active and reactive power value and P_{Li} and Q_{Li} are modified values.

At each iteration λ (Load Factor) is increased and constraints are observed and verified. On violation of any of constraint, maximum loadability is found.
Corresponding to this the objective function would be:
$J = \text{Max} \{ \lambda \}$
The constraints to be considered are as follows
$S_l \le S_{lmax}$: for all branches of the network
$|\Delta Vbi| \le 0.05$: for all buses of the network
$P_{gi}^{min} \le P_{gi} \le P_{gi}^{min}$: for all generation buses
One more constraint can be add-up is voltage angle.
$|\theta_{bi}| \le 30^{\circ}$: for all buses of the network
When any of above constraints is violated include TCSC for that load condition in all branches one by one.
If the condition is reached when there is no violation, increase the loading and generation.
In order to simplified the process, there is fitness function to sum-up constraints OVL (overload) and VLB (Bus voltage violation) the fitness function is constructed as

$$\text{Fit} = 2 - \left(\prod_{Line} \text{OVL}_{Line} + \prod_{Bus} \text{VLB}_{Bus} \right)$$

Where

$$\text{OVL}_l = \begin{cases} 1 & ;\text{if } S_l \le S_{l\max} \\ \exp\left(\mu_1 \left|1 - \frac{S_l}{S_{l\max}}\right|\right) & ;\text{if } S_l > S_{l\max} \end{cases}$$

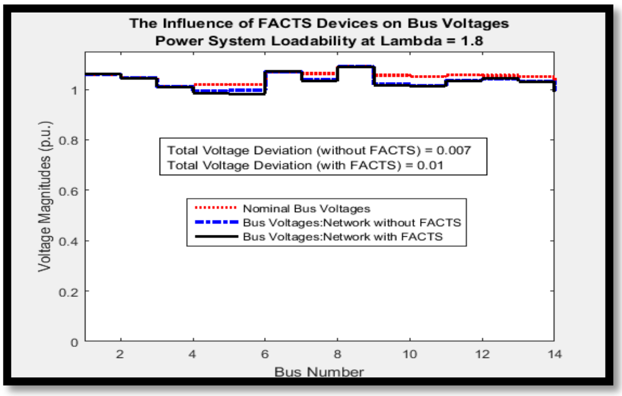
$$\text{VBL}_i = \begin{cases} 1 & ;\text{if } |\Delta V_{bi}| \le 0.05 \\ \exp\left(\mu_2 |0.05 - \Delta V_{bi}|\right) & ;\text{if } |\Delta V_{bi}| \ge 0.05 \end{cases}$$

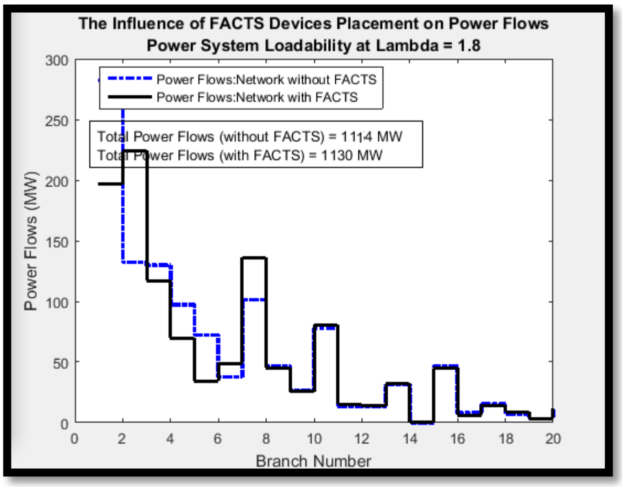
Where μ_1 and μ_2 are constant coefficient.

So, generalized process for optimization would be like:
Initialize $\lambda_0 = 1$ and select the network and desired FACTS device.
Increase, $\lambda = \lambda + 1$, create population for GA and verify the constraints by fitness function. If the fitness function value is 0, it is acceptable and we may further increase λ.
If fitness function value is not 0, there is violation of constraint.

IV. RESULT AND DISCUSSION

When incremental change in load and generation is done without FACTS devices the maximum active power generation is 522 MW. The base load is 259 MW.
The results are shown below:





By using GA the load factor could be reached up to 1.8. That means loadability is increased up to 80% of base load. The optimal location is found branch 2 with reactance value 0.7152.

V. CONCLUSION

By using single TCSC the loadability of IEEE-14 bus system is increased up to 1.8 load factor using GA. The loadability can be enhanced even more by increasing numbers of TCSC.

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