The Application Of TCSC To Improve ATC Of Power Transmission Network By Using Genetic Algorithm

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Abstract- Available Transfer Capability (ATC) of electrical power transmission network is the measure of the remaining power transfer capability of the transmission network for further transactions. It is to be declared well in advance for its commercial use in a competitive electricity market. AC Power transfer distribution factors (ACPTDFs) based approach is best for ATC determination. The Obtained results are compared with ATC calculations after TCSC (FACTS device) install. In calculation generation limits, line thermal limits and voltage limits are considered. The Genetic algorithm with MATLAB programming is considered to find best location of TCSC (FACTS device). The proposed algorithm tested on IEEE 5 and 9 bus power systems. The resulting voltage profile, loss values and ATC clearly indicate that the introduction of FACTS devices in a right location could improve ATC.

Keywords: ATC; AC power transfer distribution factors; flexible AC transmission systems; TCSC; genetic algorithm.

I.INTRODUCTION

Transfer of bulk electrical power over long distances is routing in India. So it may get deregulate.This power system structure, power producers and customers share a common transmission network, faces a new challenges and becomes more complex to build new structures. In this situation on of the best way to improve the system operation is use of FACTS devices. Alternating current transmission systems incorporating power electronic based and other static controllers to enhance controllability and increase power transfer capability called FACTS devices. Here we took the quantity Available transfer capability (ATC) improvement as an application of FACTS.

The ATC of transmission network has become essential quantity to be declared well in advance for its commercial use in a competitive electricity market. The intensive use of the interconnected network reliably, which requires knowledge of the network capability. Available Transfer Capability (ATC) is a measure of the remaining power transfer capability of the transmission network for further transactions. Its fast computation using AC PTDF based approach has been proposed for multi-transaction cases using power transfer sensitivity and Jacobian calculated uses derivatives around the operating point. The methods can be implemented for any number of transactions occurring simultaneously.

The task of calculating ATC is one of main concerns in power system operation and planning. ATC is determined as a function of increase in power transfer between different systems through prescribed interfaces. In this study calculation of ATC done by repetitive power flow and effectiveness of the devices to enhance ATC is investigated using IEEE 5 and 9 bus test systems. The genetic algorithms as a branch of artificial intelligence play an important role to place fact devices at right location.

The study paper is divided into six parts. Section II shows the details of available transfer capability principles, section III shows the computational procedure for ATC determination, section IV includes mathematical model of TCSC device, the genetic algorithm part is described in section V to optimal location of FACTS, in the final section the results and discussions are carried out.

II.AVAILABLE TRANSFER CAPABILITY PRINCIPLES

ATC is a measure of the remaining power transfer capability of the transmission network for further transaction. Mathematically, ATC is defined as the total transfer capability less the transmission reliability margin (TRM), capacity benefit margin (CBM) and sum of existing transmission commitments which includes retail customer services.

$$ATC=TTC-TRM-CBM-TC$$

2.1 TOTAL TRANFER CAPABILITY (TTC): the TTC can defined as the amount of electric power that can be transferred over the interconnected transmission network in a reliable manner while meeting all the set of defined Pre- and Post- contingency system conditions. Transfer capability is different from transmission capacity, which usually refers to the thermal limit or rating of transmission component. The capability to meet load (transfer capability) depends on several other factors such as

1. Spatial distribution
2. Diversity of generation/load
3. Network configuration.

Thus, the individual transmission line capacities or ratings cannot arithmetically add to determine the transfer capability of a transmission path.

2.2 TRANSMISSION RELIABILITY MARGIN (TRM): Defined as that amount of transmission transfer capability necessary to ensure that the interconnected transmission network is secure under a reasonable range of uncertainties in system conditions.

2.3 CAPACITY BENEFIT MARGIN (CBM): the amount of transfer capability reserved by load serving entities to ensure access to generation from interconnected systems to meet generation reliability requirements.

The procedure proposed involves the method based on multiple load flow runs AC load flow for each increment of transaction between interfaces and checks whether any of the operating conditions such as line flow limit or bus voltage limit is violated. The minimum out of the two critical transaction values is taken as the TTC for the system in that condition.

A method based on continuation power flow [4] incorporating limits of reactive power flows, voltage limits as well as voltage collapse and line flow limits is described. However, with this method the computational effort and time requirement are large. The topological information of a system is stored in matrix form and constants for different simultaneous cases and critical contingencies have been calculating beforehand and used for determination of ATC values. For very large systems, the method may be quite cumbersome. The localized linearity of the system is assumed and additional load required to hit the different limits are separately calculated and the minimum of all these is taken as ATC.

Method based on linear sensitivity factors offer a great potential for real time calculation of ATC. Use of these factors offers an approximate but extremely fast model for the static ATC determination. The new method is introduced as AC power transfer distribution factors [2] (ACPTDFs) to determine static ATC more accurately.

It is highly recognized that FACTS devices, specially the series devices such as thyristor controlled series capacitor (TCSC), thyristor controlled phase angle regulator (TCPAR), the unified power flow controller (UPFC) etc. can be applied to increase the ATC of power network. If FACTS device is placed randomly in any line, the ATC between seller bus/area and the buyer bus/ area will increase. But if FACTS device is placed at a particular line [10, 11], ATC of that line will be increased.

III.COMPUTATIONAL METHOD

AC power transfer distribution factor method:

Consider a bilateral transaction t_p between a seller bus, m and buyer bus, n. Further consider a line l, carrying a part of the transaction power. Let the line be connected between a bus-i and a bus-j. For a change in real power transaction between the above seller and buyer say by Δtp MW, if the change in transmission line quantity ql is Δql, the AC power transfer distribution factors can be defined as [6-8]:

$$\mathrm{ACPTDF}(\mathrm{ql}-\mathrm{tp}) = \frac{\Delta \mathrm{ql}}{\Delta \mathrm{tp}}$$

In this paper, the transmission quantity ql is taken as real power flow from bus-i to bus-j.

1) Computation of AC distribution factors:

The distribution factors have been computed with the base case load flow results using the sensitivity properties of the NRLF Jacobean. The procedure for calculation of these distribution factors is described below.

Consider the sensitivity relationship provided by the Newton-Raphson load flow equations in the polar coordinates for a base case load flow as:

$$\begin{bmatrix} \Delta\delta \\ \Delta V \end{bmatrix} = [S_T] \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix}$$

Where, $S_T = [J_T]^{-1}$ is a sensitivity matrix and J_T is the full Jacobean defined for all the buses except for the slack bus. At a base case load flow, if only one of the bilateral transactions, say the p^{th} transaction, between a seller bus, m and a buyer bus, n is changed by Δt_p, only the following two entries in the mismatch vector $[\Delta P, \Delta Q]^T$.

$$\Delta \mathrm{Pm} = \Delta \mathrm{tp}, \Delta \mathrm{Pm} = -\Delta \mathrm{tp}$$

With the above mismatch vector, changes in the voltage angle and voltage magnitude at all the buses can be computed from, and hence, a new voltage profile can be calculated. These can be utilized to compute new values of transmission quantity q_l and thus the change in the quantity Δq_l from the base case. Once Δq_l is known for all the lines and change in the voltage magnitude is computed at all the buses corresponding to a transaction Δt_p, the ACPTDFs for each line and buses, respectively, can be obtained from.

2) ATC determination using AC distribution factors:

ATC from a bus/zone m to another bus/zone n can be found using the AC load flow by varying the amount of transaction until one or more line flows in the transmission system considered or a bus voltage at some bus reaches the limiting value. However this method is computationally involved. Instead, the distribution factors described above can be used to quickly calculate ATC considering both the line flow limits and voltage limits, as follows.

ATC for base case, between bus/zone m and bus/zone n using the line flow limit criterion has been calculated using ACPTDFs as,

$$\mathbf{ATC = \min \left\{ \frac{P_{ij^{max}} - P_{ij0}}{PTDFij, mn}\ ij \in Nl \right\}}$$

Where

P_{ij}^{max} is the MW power flow limit of a line between bus-i and bus-j. P_{ij}^{0} is the base case power flow in the line between bus-i and bus-j. $PTD_{Fij\text{-}mn}$ is the Power Transfer Distribution Factor for the line between bus-i and bus-j, when N_l is the total no. of lines.

IV.MODELING OF TCSC

The power transmission lines are represented by lumped π equivalent parameters. The series compensator TCSC is simply a static capacitor/reactor with impedance jx_c. Figure-1 shows a transmission line incorporating TCSC.

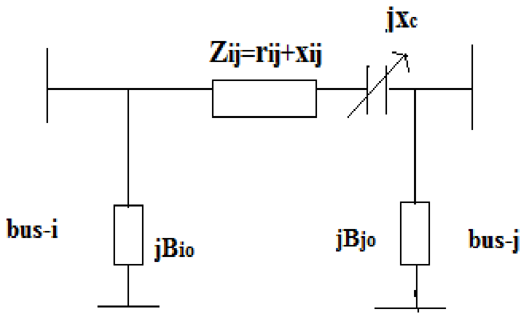


Figure-1. Equivalent circuit of a line with TCSC.

Where X_{ij} is the reactance of a line, R_{ij} is the resistance of line, B_{io} and B_{jo} are the half line charging susceptance of the line at bus-i and bus-j [9,10]

a. representation of TCSC for power flow

The difference between the line susceptance before and after the addition of TCSC can be expressed as:

$$\Delta Yij = Yij' - Yij = (gij + jbij)' - (gij + jbij)$$

$$g_{ij} = \frac{r_{ij}}{\sqrt{r_{ij}^{2} + x_{ij}^{2}}},\quad b_{ij} = -\frac{x_{ij}}{\sqrt{r_{ij}^{2} + x_{ij}^{2}}}$$

$$g'_{ij} = \frac{r_{ij}}{\sqrt{r_{ij}^{2} + (x_{ij} + x_c)^2}},\quad b'_{ij} = -\frac{x_{ij} + x_c}{\sqrt{r_{ij}^{2} + (x_{ij} + x_c)^2}}$$

After adding TCSC on the line between bus i and bus j of a general power system, new system admittance matrix $Y_{bus'}$ can be updated as:

$$Y'_{bus} = Y_{bus} + \begin{array}{cc} \left[\begin{array}{ccccccc} 0 & 0 & 0 & \cdots & 0 & 0 & 0 \\ 0 & \Delta y_{ij} & 0 & \cdots & 0 & -\Delta y_{ij} & 0 \\ 0 & 0 & 0 & \cdots & 0 & 0 & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & 0 & \cdots & 0 & 0 & 0 \\ 0 & -\Delta y_{ij} & 0 & \cdots & 0 & \Delta y_{ij} & 0 \\ 0 & 0 & 0 & \cdots & 0 & 0 & 0 \end{array}\right] & \begin{array}{l} \\ row-i \\ \\ \\ \\ row-j \\ \\ \end{array} \\ \begin{array}{ccccccc} & col-i & & & & col-j & \end{array} & \end{array}$$

Because the Y_{bus} has to be updated for each of different locations and the amount of compensation of TCSC, the above formulation is applied in each iteration

b. Power flow procedure with TCSC

The procedure for the proposed algorithm using TCSC can be summarized as:

Step 1: Read the system line data, bus data and TCSC data.

Step 2: Form Y_{bus} using sparsity technique.

Step 3: Modify the Y_{bus} elements with the value of TCSC reactance.

Step 4: Form conventional Jacobean matrix

V. CONSTRUCTION OF GENETIC ALGORITHM

In genetic algorithms [9, 11], individuals are simplified to a chromosome that codes the control variables of the problem. The strength of an individual is the objective function (fitness) that must be optimized. A random start function might generate the initial population size. After the start, successive populations are generated using the GA iteration process, which contains three basic operators: reproduction, crossover and mutation. Finally, the population stabilizes, because no better individual can be found. When algorithm converges, and most of the individuals in the population are almost identical. A genetic algorithm has three parameters: the population size, crossover rate and mutation rate. These parameters are important to determine the performance of the algorithm.

A. Presentation of control variables

To apply GA to solve a specific problem, one has to define the solution representation and the coding of control variables. The optimization problem here is to use Continuation Power Flow (CPF) to find the Total Transfer Capability for different FACTS devices locations and compensations. Every individual chromosome should contain FACTS device location and compensation level,

As for location information, we use a series of integrals to express different placement of FACTS devices. For example, if the location for FACTS device has 6 choices, six integrals 1, 2, 3, 4, 5, 6 are used as candidates for this control variable. In every procedure of GA (initialization, reproduction, crossover, mutation), the resulting location code will be held as one of those integers.

B. Initialization

The initialization procedure will select the initial population within the range of the control variables with a random number generator. The user can specify the population number in this procedure. Out of 10000 generation considered 4800 functions for 5 bus and 6800 functions for 9 bus are evaluated.

C. Fitness evaluation

After control variables are coded, the objective function (fitness) will be evaluated. These values are measures of quality, which is used to compare different solutions. The better solution joins the new population and the worse one is discarded. The fitness value of an individual will determine its chance to propagate its features to future generations. Here ATC is used as the fitness in the genetic algorithm and out of 100 iterations considered the maximum value of GA is find by sorting 30 best values in 5 bus system and 70 generations in 9 bus system.

D. Reproduction

Reproduction is a process in which individual chromosomes are copied according to their objective function (fitness), This operation is an artificial version of the Darwinian Process of natural selection. The first stage of the reproduction process is to select chromosomes for mating. The roulette wheel selection technique tested here.

E. Crossover

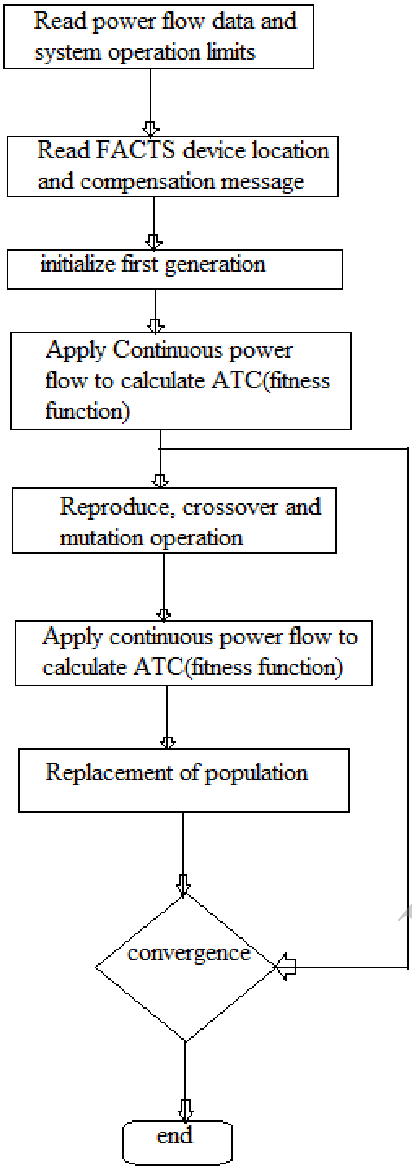
Crossover is one of the main distinguishing features of GAs that make them different from other algorithms. Its main aim is to recombine blocks on different individual to make a new one. Convex crossover is used in this work.

F. Mutation

The newly created by means of selection and crossover population can be further applied to mutation. Mutation means that some elements of chromosome are changed. Those changes are caused mainly by mistakes during the copy process of the parent’s genes.

In terms of GA, mutation means random change of the value of a gene in the population. The chromosome which gene will be changed and the gene itself are chosen by random as well.

Flow chart:



VI.CASE STUDIES AND RESULTS

The IEEE 5 and 9-bus system is adopted as the test system. The ATC has been determined using AC power transfer distribution factors method. ATC for the 5 and 9-bus system is determined for all lines transactions and also calculation is done after connecting a TCSC bus, which is given in Table-1 and 2. Results obtained from repetitive ACPTDF method before installing TCSC compared with after installing TCSC devices at appropriate location. The method run for each increment of the transaction over its base value until any of the line flows or the bus voltages hit the limiting value.

The figures show the difference in voltage values on before and after installing TCSC devices for both 5 and 9 bus system.

The connection of one TCSC in between 3 and 4th bus in 5 bus system and a new bus called TCSC bus between 7 and 6th bus with connection of lines with TCSCs from 7,4,9 in 9 bus system forms a improvement of ATC of multiple transaction.

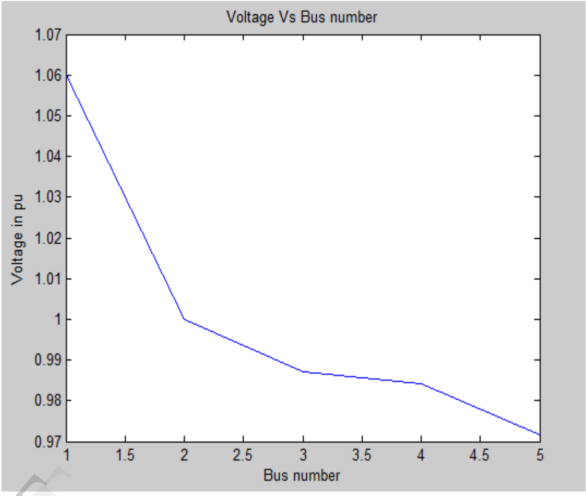


Fig.1 voltage Vs bus number before TCSC install in 5 bus system

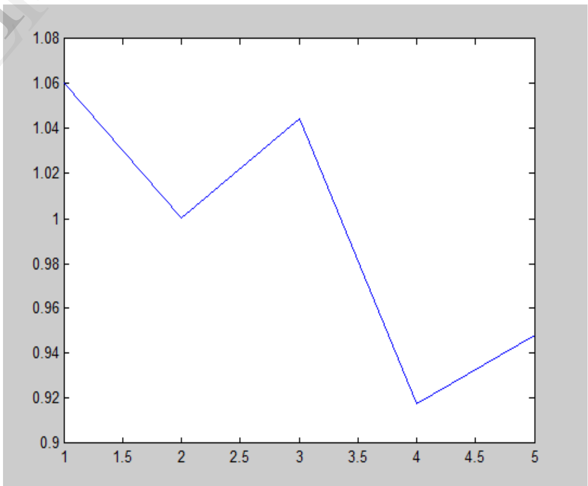


Fig.2 voltage Vs bus numbers after TCSC install in 5 bus system

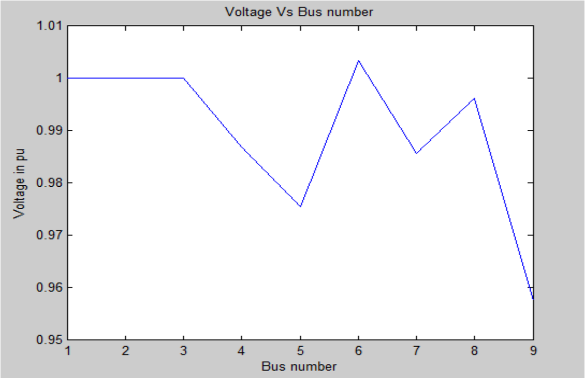


Fig.3 voltage Vs bus number before installing TCSC in 5 bus system

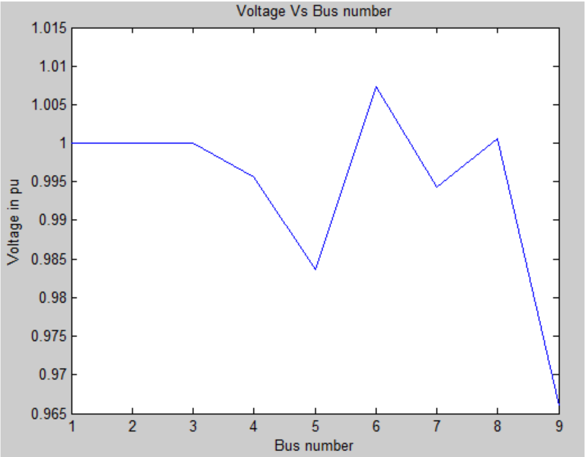


Fig.4 voltage Vs bus numbers after installing TCSC in 9 bus system

Table-1. ATC values using ACPTDFs for IEEE 5-bus

line	**From and to bus**	**Before TCSC**	**After TCSC**
1	1-2	1.2755	1.8942
2	1-3	1.2999	1.9324
3	2-3	0.3983	0.9978
4	2-4	0.3977	0.9879
5	2-5	0.3951	0.9914
6	3-4	0.4536	0.8081
7	4-5	0.3991	0.9973

Table-2. ATC values using ACPTDFs for IEEE 9-bus

Line	**From and to bus**	**Before TCSC**	**After TCSC**
1	1-4	0.7195	1.5405
2	4-5	0.0000	1.7083
3	5-6	0.9145	1.7087
4	3-6	0.8500	1.6500
5	6-7	0.0000	0.8000
6	7-8	1.0051	0.9914
7	8-2	0.0000	0.8000
8	8-9	0.0000	0.8000
9	9-4	1.2527	1.1503
10	10-4	-	3.4431
11	10-9	-	3.4498

CONCLUSIONS:

The ATC is computed for different transactions of IEEE 5 and 9- buses system using AC power transfer distribution factor method. AC power transfer distribution factor (PTDF) method have been used for ATC determination at before and after installing TCSCs, the results are compared. The results shows FACTS(TCSC) devices can be effectively improve the available transfer capability and it overcome some of the limitations of electric power transfer. The best location of devices is determined by genetic algorithm technique, the genetic algorithm is having more space search compared to others and also fast in operation.

If the computed ATC is less than the ATC of the system, the transmission of power will not be efficient economically, if the computed ATC is more than the ATC of the system, the transmission will be operating in a dangerous state and any power increased will stand a chance to collapse the whole system and the result of that is disastrous.

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