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Optimal Allocation of TCSC Devices to Optimize Total Transmission Capacity using Genetic Algorithm

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Abstract

Improving of Available Transfer Capability (ATC) is an important issue in the current de-regulated environment of power systems. The Available Transfer Capability (ATC) of a transmission network is the unutilized transfer capabilities of a transmission network for the transfer of power for further commercial activity, over and above already committed usage. Power transactions between a specific seller bus/area and a buyer bus/area can be committed only when sufficient ATC is available. Transmission system operators (TSOs) are encouraged to use the existing facilities more effectively to enhance the ATC margin. ATC can be limited usually by heavily loaded circuits and buses with relatively low voltages. It is well known that FACTS technology can control voltage magnitude, phase angle and circuit reactance. Using these devices may redistribute the load flow, regulating bus voltages.

Therefore, it is worthwhile to investigate the impact of FACTS controllers on the ATC. In this thesis focuses on the evaluation of the impact of TCSC as FACTS device on ATC and its enhancement during with and without line outage cases. In a competitive (deregulated) power market, optimal the location of these devices and their control can significantly affect the operation of the system and will be very important for ISO. Genetic Algorithm is used as the optimization tool to determine the location as well as the parameters of TCSC simultaneously.

In this thesis, the use of TCSC to maximize Available Transfer Capability (ATC) generally defined as the maximum power transfer transaction between a specific power-seller and a power-buyer in a network during normal and contingency cases.

Keywords-Active: FACTS, TCSC, ATC, GA

I .INTRODUCTION

The aim of electric industry restructuring is to promote competitive markets for electric power trading. Under new environment, the main consequence of the nondiscriminatory open-access requirement is the substantial increase in power transfers. The Available Transfer Capability (ATC) of a transmission network is the unutilized transfer capabilities of a transmission network for the transfer of power for further commercial activity, over and above already committed usage. Adequate available transfer capacity (AATC) is needed to ensure all economic transactions, while sufficient ATC is needed to facilitate electricity market liquidity. It is necessary to maintain economical and secure operation over a wide range of system operating conditions and constraints. However, tight restrictions in the construction of new facilities due to the economic, environmental, and social problems, reduces the operational alternatives. It may sometimes lead to a situation that the existing transmission facilities are intensively used. Maximum use of existing transmission assets will be more profitable for transmission system owners; and customers will receive better services with reduced prices. Various ATC boosting approaches have been experienced via adjusting generators' terminal

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voltages, under load tap changers (ULTCs) and rescheduling generator outputs. Based upon the NERC's definition of ATC and its determination [8], transmission network can be restricted by thermal, voltage and stability limits. On the other hand, it is highly recognized that, with the capability of flexible power flow, FACTS technology has introduced a severe impact to the transmission system utilization with regards to those three constraints. From the steady state power flow viewpoint, networks do not normally share power in proportion to their ratings, where in most situations, voltage profile cannot be smooth. Therefore, ATC values are always limited by heavily loaded buses with relatively low voltage. FACTS concept makes it possible to use circuit reactance, voltage magnitude, and phase angle as controls to redistribute line flow and regulate voltage profile. Theoretically FACTS devices can offer an effective and promising alternative to conventional methods of ATC enhancement. They will provide new control facilities, both in steady state power flow control and dynamic stability control [3]. Controlling power flow in electric power systems without generation rescheduling or topological changes can improve the network performance considerably. With suitable location, the effect of a TCSC on the ATC enhancement are studied and demonstrated through case studies. It is shown that installing TCSC in the proper location will improve voltage profile as well as ATC.

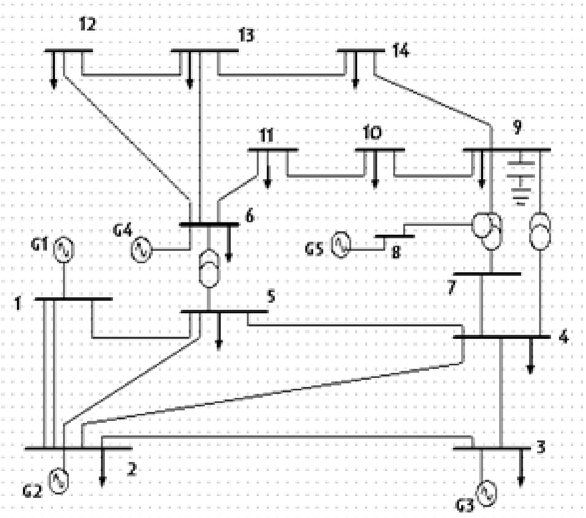

Fig.A.1: IEEE 14 bus test system

II. Overview of Available Transfer Capability

2.1 Introduction:

In a deregulated power system structure, power producers and customers share a common transmission network for wheeling power from the point of generation to the point of consumption. All parties in this open access environment may try to produce the energy from the cheaper source for greater profit margin, which may lead to overloading and congestion of certain corridors of the transmission network. This may result in violation of line flow, voltage and stability limits and thereby undermine the system security. Utilities therefore need to determine adequately their "Available Transfer Capability (ATC)" to ensure that system reliability is maintained while serving a wide range of bilateral and multilateral transactions[8].

The ATC of a transmission network has been defined as the unutilized transfer capability of the transmission network for the transfer of power for further commercial activity, over and above already committed usage. Power transactions between a specific seller bus/area can be committed only when sufficient ATC is available for that interface. Thus, such transfer capability can be used for reserving transmission services, scheduling firm and non-firm transactions and for arranging emergency transfers between seller bus/areas or buyer bus/areas of an interconnected power system network. ATC among areas of an interconnected power system network and also for critical transmission paths between areas are required to be continuously computed, updated and posted to OASIS following any change in the system conditions.

2.2 ATC Definitions:

Available Transfer Capability (ATC) is a measure of the transfer capability remaining in the physical transmission network for further commercial activity over and above already committed uses. Mathematically, ATC is defined as the Total Transfer Capability (TTC) less the Transmission Reliability Margin (TRM), less the sum of existing transmission commitments (which includes retail customer service) and the Capacity

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Benefit Margin (CBM), shown in Fig. 2.1 [8]. Total Transfer Capability (TTC) is defined as the amount of electric power that can be transferred over the interconnected transmission network in a reliable manner while meeting all of a specific set of defined pre- and post contingency system conditions.

ATC= TTC-TRM-{ETC+CBM}

III Modeling of TCSC

3.1 Introduction:

Power system is to be continuously expanded and upgraded to cater the ever-growing power demand. Due to limited energy resources, time and capital required, the present trend is looking for the new techniques for improving the power system performance. A new technology consisting of FACTS controllers has the ability to control the interrelated parameters that govern the operation of transmission system including series impedance, shunt admittance, current, voltage, phase angle and damping of oscillations at various frequencies below rated frequency. FACTs controller enables a line to carry power closer to its thermal rating. FACTs devices are the alternative transmission system incorporating power electronic based static controllers to enhance controllability and increase power transfer capability. Flexibility of AC transmission system refers to the ability to accommodate changes in the electric transmission system or operating conditions, while maintaining sufficient transient and steady state stability limit of the system.

FACTS devices may be used to achieve several goals in power systems. In steady-state, for a meshed network, they permit transmission lines to be operated close to their thermal limits and reduce the loop flows. In this respect, they can be used to supply or absorb the reactive power, to increase or decrease voltages and to control the series impedance or the phase-angle.

Consider a two-machine model that is connected through a transmission line as shown in fig. 3.1 [2].

In an electrical network, value of the line conductance is close to zero and for most transmission lines; the line resistance is small compared to its reactance. By neglecting the line capacitance, the active and reactive powers transmitted by the line between two buses 1 and 2 may be approximated by the following equations:

$$P_{12} = \frac{V_1 V_2}{X_{12}} \sin\theta_{12} \quad (3.1)$$

$$Q_{12} = \frac{1}{X_{12}}(V_1^2 - V_1 V_2 \cos\theta_{12}) \quad (3.2)$$

Where V1 and V2 are the voltages at buses 1 and 2, X12 is the line reactance and θ12 is the angle between V1 and V2. In high voltage transmission lines, V1 ≈V2 and θ12 is typically small. So there is a decoupling between controls of flows of the active versus reactive power. The active power flow is coupled with θ12 and the reactive power flow is linked to the difference (V1-V2). The control of X12 affects on both and modifies the active and reactive powers. Series Compensation permits to modify the reactance of the line X12 [1], and shunt compensation controls the voltage magnitudes of the load bus.

3.4 Series Compensation:

3.4.1 Introduction

As modern transmission systems become more and more heavily loaded the benefits of series compensation for many of the grid’s transmission lines become more obvious. Clearly, adding series compensation is one of the cheapest, simplest ways of increasing transmission line capacity and system stability, lowering losses, and improving voltage regulation. Series compensation systems use capacitors to decrease the equivalent reactance of a power line at rated frequency. The connection of a series capacitor generates reactive power that, in a self-regulated manner, balances a fraction of the line's transfer reactance.

3.4.2 Modeling of TCSC:

Transmission lines are represented by lumped π equivalent parameters. The series compensator TCSC is

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simply a static capacitor/reactor with impedance jxc [2]. Fig. 3.2 shows a transmission line incorporating a TCSC.

Bus-i

Bus-j

Where Xij is the reactance of the line, Rij is the resistance of the line, Bio and Bjo are the half-line charging susceptance of the line at bus-i and bus-j.

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

$$\Delta y_{ij} = y_{ij}^{'} - y_{ij} = (g_{ij}^{'} + jb_{ij}^{'}) - (g_{ij} + jb_{ij}) \quad (3.3)$$

$$g_{ij} = \frac{r_{ij}}{\sqrt{r_{ij}^{2} + x_{ij}^{2}}} \quad b_{ij} = -\frac{x_{ij}}{\sqrt{r_{ij}^{2} + x_{ij}^{2}}} \quad (3.4)$$

$$g_{ij}^{'} = \frac{r_{ij}}{\sqrt{r_{ij}^{2} + (x_{ij} + x_{c})^{2}}} \quad b_{ij}^{'} = -\frac{x_{ij} + x_{c}}{\sqrt{r_{ij}^{2} + (x_{ij} + x_{c})^{2}}} \quad (3.5)$$

After adding TCSC on the line between bus i and bus j of a general power system, the new system admittance matrix Y'bus can be updated as [2]:

RGA for enhancement of ATC using FACTs Devices

4.1 Introduction

Genetic Algorithms (GAs) were invented and developed by John Holland. He invented genetic algorithm with decision theory for discrete domains. Holland emphasized the importance of recombination in large populations.

Genetic algorithms are search algorithms based on the mechanics of natural selection and natural genetics, inspired from the biological evolution, survival of the fittest among string structures with a structured yet, randomized information exchange with in the population to form a search algorithm with some of the innovative flair of human search. In every generation a new set of artificial creatures (strings) created using bits and piece of the old, an occasional new part is tried for good measure. Being randomized GAs exploit historical information to speculate on new search points with expecting improved performance. The current literature identifies three main types of search methods or optimization techniques. They are:

(i)Calculus –based method

(ii)Enumerate method

(iii)Random search techniques

Calculus based and enumerative methods are comfortable in their ability to deliver solutions in applications involving search spaces of limited problem domain. Both methods are local in scope; the optima they seek are the best in a neighborhood of the current search point. But in their application to real world of search, which is fraught with discontinuities of functions and their derivatives and vast multi-modal noisy search spaces, they break down on problems of even moderate size and complexity. Their inability and inefficiency to overcome the local optima and reach the global optimum make them insufficiently robust, precluding their application to complex problems as search method.

On the other hand, random search algorithms managed to overcome the inherent disabilities of the calculus and enumerative methods. Yet, random schemes that searches and save the best must also be discounted because of the efficiency requirement. Random searches, in the long run can be expected to do no better than enumerative schemes. In our haste to discount strictly random search methods, we must be careful to separate them from randomized techniques.

The randomized search techniques incorporated the basic advantages of random search but used it only as a tool to guide a more highly exploitative search. In these methods, the search is carried out randomly and information gained from a search is used in guiding the next search. Genetic algorithm is an example of such technique, which drew inspiration from the robustness of nature.

GAs are different in the following aspects:

(i)GAs work with a coding of the parameter set, not the parameters themselves.

(ii)GAs searches from a population of points, not from a single point as in conventional search algorithms.

(iii)GAs uses objective function information, not derivatives or other auxiliary knowledge.
(iv)GAs use probabilistic tradition rules but not deterministic rules.

4.2 Phases of Genetic Algorithm

The first step in Genetic Algorithm is the random generation of large number of search points from the total search space. Each and every point in the search space corresponds to one set of values for the parameters of the problem. Each parameter is coded with a string of bits. The individual bit is called "gene". The content of each gene is called "allele". The total string of such genes of all parameters written in a sequence is called "chromosome". So, there exists a chromosome for each point in the search space. The set of search points selected and used for processing is called a "population". i.e. population is a set of chromosomes. The number of chromosomes in a population is called "population size" and the total number of genes in a string is called "string length". The population is evaluated through various operators of GA to generate a new population. This process is carried out until global optimum point is reached.

Typically it consist of three phases,
(i)Generation
(ii)Evaluation
(iii)Genetic operation

Generation

In this phase number of chromosomes equal to population size is generated and each is of length equals to string length. The size of population is direct indication of effective representation of whole search space in one population. The population size affects both the ultimate performance and efficiency of GA. If it is too small it leads to local optimum solution. The selection of string length depends on the accuracy and resolution requirement of the optimization problem. The higher the string length, the better the accuracy and resolution. But this may lead to slow convergence. Also, the number of parameters in the problem will have a direct effect on the string length of the chromosome, for a particular resolution and accuracy requirements the string length is chosen appropriately. The chromosome should in some way contain the information about solution, which it represents. After the selection of string length and population size, the initial population is encoded. Most commonly used encoding schemes are:

a) Binary encoding

In binary encoding every chromosome is a string of bits 0 or 1. The chromosome looks like
Chromosome 1: 110110010011
Chromosome 2: 110111100001

Each chromosome has one binary string. Each bit in this string can represent some characteristic of the solution or the whole string can represent a number.

b) Permutation encoding

In permutation encoding every chromosome is a string of numbers, which represent number in a sequence. Permutation encoding is only useful for ordering problems. The chromosomes in this encoding looks like
Chromosome 1: 1 5 3 2 6 4 7 9 8
Chromosome 2: 8 5 6 7 2 3 1 4 9

c) Value encoding

Direct value encoding can be used in problems, where some complicated value, such as real numbers, is used. Use of binary encoding for this type of problems would be very difficult. In the encoding, every chromosome is a string of some values. Values can be anything connected to problem, real numbers or characteristics to some complicated objects. The chromosomes in this encoding looks like:
Chromosome 1: 1234 5.3243 0.4556 2.3293 2.4545
Chromosome 2: ABDJEIFJDHDIERJFDLDFLFEGT

Value encoding is very good for some special problems. On the other hand, for this encoding is often necessary to develop some new crossover and mutation specific for the problem.

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Random generation techniques are used in accomplishing this task. Any of the encoding techniques can be used but binary encoding is mostly used.

Now, the initial population of chromosomes is decoded and all the parameters are calculated for each chromosome. This results in a set of solutions whose size is equal to population size.

Evaluation

In the evaluation phase, suitability of each of the solutions from the initial set as the solution of the optimization problem is determined. For this function called "fitness function" is defined. This is used as a deterministic tool to evaluate the fitness of each chromosome. The optimization problem may be minimization or maximization type. In the case of maximization type, the fitness function can be a function of variables that bear direct proportionality relationship with the objective function. For minimization type problems, fitness function can be function of variables that bear inverse proportionality relationship with the objective function or can be reciprocal of a function of variables with direct proportionality relationship with the objective function. In either case, fitness function is so selected that the most fit solution is the nearest to the global optimum point. The programmer of GA is allowed to use any fitness function that adheres to the above requirements. This flexibility with the GA is one of its fortes.

On the whole for a typical optimization problem, evaluation phase consists of calculation of individual parameters, testing of any equality or inequality constraints that need to be satisfied, evaluation of objective function, and finally evaluation of fitness from fitness function. This evaluation is discrete in nature vis-à-vis some genetic operators which operate on more than one chromosome at a time.

Genetic operation

In this phase, the objective is the generation of new population from the existing population with the examination of fitness values of chromosomes and application of genetic operators. These genetic operators are reproduction, crossover, and mutation. This phase is carried out if we are not satisfied with the solution obtained earlier. The GA utilizes the notion of survival of the fittest by transferring the highly fit chromosomes to the next generation of strings and combining different strings to explore new search points.

Reproduction

Reproduction is simply an operator where by an old chromosome is copied into a Mating pool according to its fitness value. Highly fit chromosomes receive higher number of copies in the next generation. Copying chromosomes according to their fitness means that the chromosomes with a higher fitness value have higher probability of contributing one or more offspring in the next generation.

Crossover

It is recombination operation. Here the gene information (information in a bit) contained in the two selected parents is utilized in certain fashion to generate two children who bear some of the useful characteristics of parents and expected to be more fit than parents.

There are various techniques that are used for performing this crossover. But first of all we need to pick up two parents from the existing population to perform crossover. This selection can be done using two methods.

a) Random selection

b) Roulette Wheel selection

In the random selection technique, the parents are picked up randomly from the existing population. In roulette wheel selection technique, selection is usually implemented as a linear search through roulette wheel with slots weighed in proportion to string fitness values.

This is achieved using the following steps.

(i) Total sum of the fitness' (fitsum) of all the strings is calculated.

(ii) A random real number (rand-sum) between 0 and fitsum is generated.

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(iii) Starting with the first member of existing population, for each member 'n' the fitness sum of members '1' to 'n' is compared with the randomly generated number.
(iv) If Σ (fitness of member n) > rand-sum, n is selected as parent. Otherwise the process is continued by incrementing n.

The Available Transfer Capability (ATC) are computed for a set of source/sink transfers on IEEE 14-bus system. The ATC margin can be further increased by proper location and control parameter of FACTs devices. In this thesis, TCSCis used as FACTs devices. Real-code Genetic Algorithm is used to find optimal location and control parameter of TCSC for maximizing of ATC. In this thesis, the total study is divided into two cases as:
1. ATC calculation without line outage.
2. ATC calculation with line outage.

The ATC margin is limited by bus voltage magnitude and line flow rating. The voltage magnitude limits of all buses are set to Vmin=0.95 (p.u) and Vmax=1.15 (p.u). The line ratings of IEEE 14-bus system are given in appendix A.

5. RESULTS

5.1.1 without line outage case

Table-5.1: ATC without FACTS Device

Source bus/Destination bus	ATC (MW)	Violation Constraint (line flow/voltage)
¼	226.7462	Line-1 overflow
1/3	165.1349	Line-2 overflow
1/10	51.8619	Line-8 overflow
1/13	29.6155	Line-8 overflow
1/14	41.1394	Line-8 overflow

The Available Transfer Capability (ATC) are computed for a set of source/sink transfers using AC Power Transfer Distridution Factors method (ACPTDF).

5.1.2. Incorporation of TCSC

When TCSC is incorporated in the system, if we consider all lines of system, there are 20 possible locations for the TCSC. The location code region are set as 20 integers as 1 to 20. The amount of compensation offered by TCSC is 0 to 40% (Ks). After using Real Genetic Algorithm proposed in this work, the results obtained are shown in Table-5.2. It shows that with the flow control function TCSC increased the ATC significantly.

Table-5.2: ATCs after incorporating TCSC

Source bus/Destinatio n bus	ATC withou t TCSC (MW)	ATC with TCSC(MW)	Locatio n of TCSC	Compensatio n
¼	226.75	234.04	Line 7	-0.037
1/7	59.97	73.10	Line 9	-0.186
1/12	28.42	72.27	Line 8	-0.166
2/10	52.59	59.98	Line 8	-0.239
2/12	28.64	55.46	Line 8	-0.116

Fig. 5.1 is the convergence characteristic of Real-code Genetic Algorithm and it shows a graph between generation and fitness function i.e., ATC (M.W) when source/sink transfer is between bus 1 and bus 9. After 89 generations, the optimal value of TCSC location and compensation value are found. It shows a good convergence of this algorithm.

The GA parameters selected were:
a) Population size = 40
b) Elitism probability = 0.15
c) Crossover probability = 0.60
d) Mutation probability = 0.01
e) Generations number = 100.

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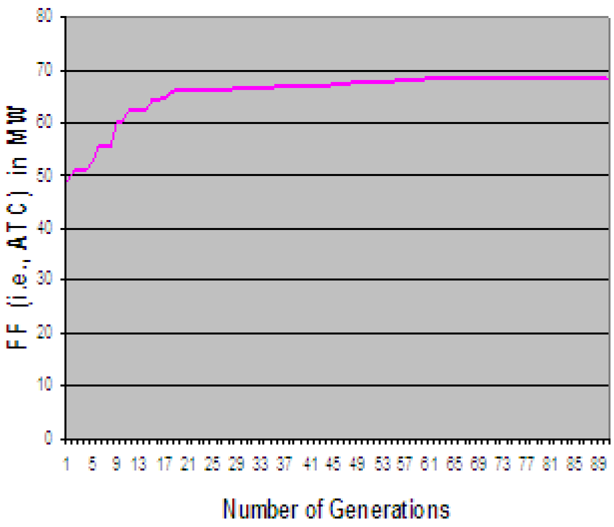

Fig. 5.1: No. of Generations Vs Fitness profile of ATC

5.1.3. With line outage

The Available Transfer Capability (ATC) are computed for a set of source/sink transfers using AC Power Transfer Distibution Factors Method (ACPTDF), when line-16 is physically removed from the system that is connected between bus-13 and bus-14. Table-5.3 shows the ATCs for IEEE 14-bus system without FACTs device, when line-16 is outage. Fig. 5.3: Shows a graph voltage profile for the IEEE 14-bus system with and without outage cases.

Table-5.3: ATCs without FACTS Device during Line-16 outage

Source/Sink bus no.	ATC (M.W)	Violation Constraint (line flow/voltage)
1/9	45.0	Bus-14 voltage limit
1/10	44.0	Bus-10 voltage limit
1/12	34.5	Line-8 overflow
1/13	22.5	Bus-13 voltage limit
1/14	36.0	Bus-14 voltage limit
1/4	217.0	Line-7 overflow
1/3	157.5	Line-2 overflow

5.1.3.1 Incorporation of TCSC

When one TCSC is incorporated in the system, if we consider all lines of system, there are 19 possible locations for the TCSC. The location code region are set as 20 integers as 1 to 20 except line 16. The amount of compensation offered by TCSC is 0 to 40% (Kd). After using Real Genetic Algorithm proposed in this work, the results obtained are shown in Table-5.4. It shows that with the flow control function TCSC increased the ATC significantly even under line outage.

Table-5.4: ATCs after incorporating TCSC during line-16 outage

Source/Sink bus no.	ATC without TCSC (M.W)	ATC with TCSC (M.W)	TCSC Location	Compensation (p.u)
1/9	45.0	61.0	Line-6	-0.089
1/10	44.0	56.5	Line-6	-0.100
1/12	34.5	46.0	Line -12	-0.055
1/13	22.5	39.0	Line -9	-0.084
1/14	36.0	51.0	Line -12	-0.066
1/4	217.0	230.0	Line -8	-0.100
1/3	157.5	187.5	Line -6	-0.102

CONCLUSION

In deregulated power systems, available transfer capability (ATC) analysis is presently a critical issue either in the operating or planning because of increased area interchanges among utilities. Sufficient ATC should be guaranteed to support free market trading and maintain an economical and secure operation over a wide range of system conditions. However, tight restrictions on the construction of new facilities due to the increasingly difficult economic, environmental, and social problems, have led to a much more intensive shared use of the existing transmission facilities by utilities and independent power producers (IPPs). Based on operating limitations of the transmission system and control capabilities of FACTS technology, technical feasibility of applying FACTS devices to boost ATCs are analyzed and identified.

The ATC is computed for various transactions using AC Power Transfer Distridution Factors method on IEEE 14-bus test system during normal case considering line thermal limit as well as bus voltage limit. The improvement of ATC using TCSC is studied and demonstrated with IEEE 14-bus test system during normal case. The location and control parameter of TCSC in the system also affects the enhancement of ATC. Implementation of the proposed Real code Genetic Algorithm has performed well when it is used to determine the location and compensation level of TCSC with the aim of maximizing the Available Transfer Capability. From the results, it is shown that TCSC can improve ATC in both thermal dominant case and voltage dominant case.

However, further studies are required in two respects. First, these results need to be compared with those obtained using some other techniques to determine its relative benefits. Secondly, studies on large practical system with more numbers of TCSCS should be conducted.

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