Improvement and Comparison of ATC using Facts with Expert Systems

G.S.S. Manikanta[1], M.R.P. Reddy[2], Ch. Rambabu[3]
Electrical and Electronics Engineering Department,
Sri Vasavi Engineering College, Tadepalligudem, Andhra Pradesh, INDIA

Abstract

In this paper the Improvement and comparison of ATC in current De-Regulated environment was discussed. In order to facilitate the electricity market operation and trade in the restructured environment, ample transmission capability should be provided to satisfy the demand of increasing power transactions. The conflict of this requirement and the restrictions on the transmission expansion in the restructured electricity market has motivated the development of methodologies to enhance the available transfer capability (ATC) of existing transmission grids. which is computed using proposed technique named by Continuous Power Flow (CPF). In order to have improvement in ATC, Flexible AC Transmission System (FACTS) devices are used to control power flow (PF), thus improve the power profile in the transmission system. In this paper the Expert System is used which is nothing but RGA(Real code Genetic Algorithm) is used as the optimization tool to determine the location as well as the controlling parameter of FACTS Devices, these FACTS Devices can control voltage magnitude, phase angle and circuit reactance. Using these devices may redistribute the load flow, regulating bus voltages. The performance of Expert system has been tested on IEEE-14, IEEE-24&IEEE-75 bus systems.

Keywords

ATC, FACTS Devices, power seller/buyer, Load flows, Expert system, RGA.

1. Introduction

Nowadays, power system encounters several new challenges according to the energy conversion of some countries from regulating power system structure into deregulating structure in a reliable and economic power supply perspective. It is thought that the heightened number of potential producers patronized by the consumers is considered as major defining role for the success of a competitive market. The transmission lines in an open market have experienced certain restrictions in order to establish the expansion of transmission grids that will be subjective to defining factors such as environment concerns, right of way, cost consuming time and soon. Since electricity serves as an essential commodity, the markets have been prompted to developing a mode of improvement called Available Transfer Capability (ATC). 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. Numerous researches have been focused on establishing the optimal location of FACTS and ATC computation either by presenting them together at the same time or they are analyzed individually. Maximum use of existing transmission assets will be more profitable for transmission system owners; and customers will receive better services with reduced prices [3]. Various ATC boosting approaches have been experienced via adjusting generators' terminal voltages, under load tap changers and rescheduling generator outputs. Based upon the NERC's definition of ATC and its determination [2], 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 [4], FACTS technology has introduced a severe impact to the transmission system utilization with regards to those three constraints. It is shown that installing FACTS Devices in the proper location will improve voltage profile as well as ATC.

2. Modelling of FACTS Devices

Power system is to be continuously expended and upgraded to cater the ever-growing power demand due to limited energy recourses, 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 inter related parameters that govern the operation of transmission on system including series impedance ,shunt admittance, current ,voltage ,phase angle and damping of oscillations at various frequencies below rated frequency. FACTS refer to the ability to accommodate changes in the electric transmission system maintains stedy state limit[1].

a. Benefits of FACTS devices

There is a better utilization of existing transmission system assets. Building new transmission lines to meet the increasing electricity demand is always limited economically and by environmental constraints and FACTS devices meet these requirements using the existing transmission systems. Increase in dynamic and transient grid stability and reduction of loop flows is achievable as FACTS devices can stabilize transmission systems with higher energy transfer capability and reduction in risks of line trips. In fact FACTS devices help to distribute electricity more economically through better utilization of existing installations thereby reducing the need for additional transmission lines [1].

b. Modeling of TCSC

Transmission lines are represented by lumped π equivalent parameters. The series compensator TCSC is simply a static capacitor/reactor with impedance jxC [4]. Fig.1. shows a transmission line incorporating a TCSC, 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.

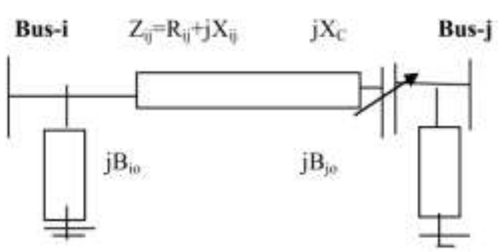


Fig. 1. Equivalent circuit of a line with TCSC

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

$$g_{ij} = \frac{r_{ij}}{\sqrt{r_{ij}^{\ 2} + x_{ij}^2}},\ b_{ij} = -\frac{x_{ij}}{\sqrt{r_{ij}^2 + x_{ij}^2}} \quad \text{----} \quad (1)$$

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

After adding TCSC on the line between bus i and bus j in a general power system, the new system admittance matrix Y'_{bus} can be updated as [11]:

$$Y'_{bus} = Y_{bus} + \begin{bmatrix} 0 & 0 & 0 & \cdots & 0 & 0 & 0 \\ 0 & \Delta y_{ij} & 0 & \cdots & 0 & -\Delta y_{ij} & 0 \\ 0 & 0 & 0 & \cdots & 0 & 0 & 0 \\ \cdots & \cdots & \cdots & \cdots & 0 & \cdots & 0 \\ 0 & 0 & 0 & \cdots & 0 & 0 & 0 \\ 0 & -\Delta y_{ij} & 0 & \cdots & 0 & \Delta y_{ij} & 0 \\ 0 & 0 & 0 & \cdots & 0 & 0 & 0 \end{bmatrix} \begin{matrix} \\ r-i \\ \\ \\ \\ r-j \\ \\ \end{matrix}$$

$$\qquad col-i \qquad\qquad col-j$$

c. Percentage Series Compensation (Ks):

The percentage or the degree of series compensation is used to analyze a transmission line with the required addition of series capacitors. It is defined as the fraction of Xc, which refers to the total capacitive reactance of series compensators and X l, which refers to the total inductive reactance of the line, as defined in Eqn. below [5].

$$K_S = X_C / X_{ij}$$

d. Modeling of SVC

The shunt compensator SVC is simply a static capacitor/ reactor with susceptance Bsvc [6].

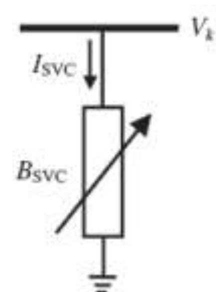


Fig. 2. Variable shunt susceptance

Fig. 2 shows the equivalent circuit of the SVC can be modeled as a shunt-connected variable susceptance BSVC at bus-i. The reactive power injected into the bus due to SVC can be expressed as

$$Q_{SVC} = B_{SVC} V^2$$

Where V is the voltage magnitude of the bus at which the SVC is connected. Fig. 3 shows the steady-state and dynamic voltage-current characteristics of the SVC portion of the system. At the capacitive limit, the SVC becomes a shunt capacitor. At the inductive limit, the SVC becomes a shunt reactor (the current or reactive power may also be limited). The response shown by the dynamic characteristic is very fast (few cycles) and is the response normally represented in transient stability simulation. Some SVCs have a susceptance/current/reactive power regulator to slowly return the SVC to a desired steady-state operating point. This prevents the SVC from drifting towards its limits during normal operating conditions, preserving control margin for fast reaction during disturbances. During normal operation, voltage is not regulated unless the voltage exceeds a dead band determined by the limits on the output of the susceptance regulator.

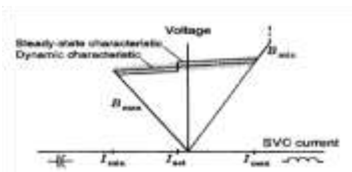


Fig. 3: SVC static characteristics at high voltage bus.

After adding SVC at bus-i of a general power system, the new system admittance matrix Y'bus can be updated as [6].

$$Y_{bus}^{'} = Y_{bus} + \begin{bmatrix} 0 & 0 & 0 & \dots & 0 & 0 & 0 \\ 0 & Y_{shunt} & 0 & \dots & 0 & 0 & 0 \\ 0 & 0 & 0 & \dots & 0 & 0 & 0 \\ \dots & \dots & \dots & \dots & 0 & \dots & 0 \\ 0 & 0 & 0 & \dots & 0 & 0 & 0 \\ 0 & 0 & 0 & \dots & 0 & 0 & 0 \\ 0 & 0 & 0 & \dots & 0 & 0 & 0 \end{bmatrix} \begin{matrix} \\ r-i \\ \\ \\ \\ r-j \\ \\ \end{matrix}$$
$$\qquad\qquad col-i \qquad\qquad col-j$$

e. Degree of Shunt Compensation (Kd):

In many investigations of determining the maximum power transfer, the amount of shunt reactors required on the transmission line is defined as the degree of shunt compensation (K_d), where

$$\boldsymbol{K_d = B/Imag\{y\}'}$$

K_d is defined as the fraction of the total Inductive susceptance of shunt compensation (B) and the total charging susceptance of line[5].

Optimal SVC planning is necessary in order to achieve enhancement of power system reactive power (VAr) margin, reduction in system losses and voltage depressions at critical points.

3. RGA for Enhancement of ATC using FACTS Devices

Genetic Algorithms (GAs) were invented and developed by John Holland. He invented genetic algorithm with decision theory for discrete domains. 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.

A. 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". After 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 coding:

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: 1234 5.3243 0.4556 2.3293
Chromosome 2: ABDJEIFJDHDIERJFDLDFLFEGT

B. Phases of Real-code Genetic Algorithm

RGA is similar to normal GA except decoding the control variable information is eliminated; hence it will reduce the computation time. In RGA the control variable information is encoded in the form of real value, hence it will avoid the usage of decoding process. The differences between GA and RGA are tabulated in Table A.

Table A
Genetic Algorithm Vs Real-code Genetic Algorithm

	GA	RGA
Controlvariable information in chromosome	In the form of binary	In the form of real value
Decoding process	Required	Not required
Selection process	Required	Required
Crossover Operator	Required	Required
Mutation operator	Required	Required

4. RGA for Enhancement of ATC using FACTS Device: Algorithm

1. Read the power system data

   a. Read system line and bus data.
   b. System data: From bus, to bus, line resistance, line reactance, half –line charging Susceptance, off nominal turn's ratio, maximum line flow.

2. Bus data: Bus no, Bus type, Pgen, Qgen, Pload, Qload, Pmin, Pmax,Vsp Shunt capacitor data.

   a. Read data for genetic operations
   b. Read no.of control variables i.e. TCSC/SVC location and reactance/susceptance
   c. Read maximum line flow limits, load bus voltage limits.
   d. Read the sending bus (seller bus) *m* and the receiving bus (buyer bus) *n*.
   e. Calculate Pshed(i), Qshed(i),

   for i=1 to no. of buses
   Where
   Pshed(i)=Pgen(i)-Pload(i)
   Qshed(i)=Qgen(i)-Qload(i)

Form Ybus using sparsity technique E=complex (Vsp,0)

3. Generate population size of chromosomes randomly

(i) gen=1, generation count

(ii) (a) k1=1, chromosome count
(b) Using the line no./bus no. and reactance/susceptance information modify Y-bus

(iii) Calculate ATC using NR repeated power flow

(iv) Calculate fitness (k1) = ATC (i.e. maximization)
If (k1< population size)
k1=k1+1 go to (iv) (b) Else go to (vii)

(v) Check the termination criteria i.e. the difference between first chromosome fitness value and last chromosome fitness value will be certain tolerance. If the condition is satisfied stop the process otherwise go to step (ix)

(vi) Arrange chromosomes in descending order of their fitness values

(vii) Copy elitism probability of chromosomes to next generation and perform roulette wheel reproduction technique for parent selection.

(viii) If (r<Pc) perform cross over to obtain children of next generation using the following equation, where r is a randomly generated number between 0 and 1 and Pc is the cross over probability.

where x, y are the two parents, x', y' are their two offspring. 1 and 2 is obtained by a uniform random number generator between the range (0~l). Perform mutation i.e.

(ix) If (gen < genmax)
gen = gen+1 and go to step (iv)(a) Else go to step (xiv)

(x) Print optimized values i.e. line no, compensation and ATC values for each transaction.

5. Case Study and Discussion

The Available Transfer Capability (ATC) are computed for a set of source/sink transfers on IEEE 14,IEEE-24 IEEE-75bus reliability test system. The ATC margin can be further increased by proper location and control parameter of FACTs devices. In this thesis, TCSC and SVC are used as FACTs devices. Real-code Genetic Algorithm is used to find optimal location and control parameter of TCSC and SVC for maximizing of ATC. The ATC margin is limited by bus voltage magnitude and line flow rating. The voltage magnitude limits of all buses are set to V_{min}=0.95 (p.u) and V_{max}=1.15 (p.u).

A. IEEE-14 BUS Reliability Test System

a. Without FACTS:

The Available Transfer Capability (ATC) is computed for a set of source/sink transfers using Continuous Power Flow (CPF). Table-1 shows the ATCs for IEEE 14-bus system without FACTs device.

Table-1: IEEE-14 BUS without FACTS

Source bus no.	ATC (M.W)	Violation Constraint (Lineflow/voltage)
1/9	64.71	Line-8 overflow
1/10	51.86	Line-8 overflow
1/12	28.42	Line-8 overflow
1/14	41.14	Line-8 overflow
1/4	226.75	Line-1 overflow

b. Incorporation with TCSC:

When TCSC is incorporated in the system, if we consider all lines of system, there are 20 possible locations for the TCSC. 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-2.

Table-2: IEEE-14 BUS Incorporation with TCSC

Source bus no.	ATC without TCSC	ATC with TCSC	TCSC Location	Compensation (p.u)
1 /9	64.71	77.28	Line-12	-0.2433
1/10	51.86	60.07	Line-13	-0.2429
1/12	28.42	73.69	Line -12	-0.1782
1/14	41.14	60.53	Line-8	-0.2208
1/4	226.75	243.24	Line -7	-0.0408

c. Incorporation with SVC:

When one SVC is incorporated in the system, if we consider all buses of system, there are 14 possible locations for the SVC. The amount of compensation offered by SVC is 0 to 0.1 (p.u) i.e., Bsvc. After using Real Genetic Algorithm, the results obtained are shown in Table-3.

Table-3: IEEE-14 BUS Incorporation with SVC

Source bus no.	ATC without SVC	AT with SVC (M.W)	SVC Location	Compen(p.u)
1 /9	64.71	71.75	Bus-9	-0.2372
1/10	51.86	54.15	Bus-9	-0.2042
1/12	28.42	60.91	Bus-9	-0.1419
1/14	41.14	54.37	Bus-12	-0.1762
1/4	226.75	235.72	Bus-7	-0.0464

B. IEEE-24 BUS Reliability Test System

a. Without FACTS:

The Available Transfer Capability (ATC) is computed for a set of source/sink transfers using Continuous Power Flow (CPF). Table-4 shows the ATCs for IEEE 24-bus system without FACTs device.

Table-4: IEEE-24 BUS without FACTS

Source bus no.	ATC (M.W)	Violation Constraint (Line flow/Voltage)
23/15	778.76	Line-24 overflow
22/9	404.43	Bus-9 voltage limit
22/5	255.68	Line-9 overflow
21/6	103.98	Line-10 overflow
18/5	255.89	Line-9 overflow

b. Incorporation with TCSC:

When TCSC is incorporated in the system, if we consider all lines of system, there are 38 possible locations for the TCSC. 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

Table-5: IEEE-24 BUS Incorporation with TCSC

Source bus no.	ATC without TCSC	ATC with TCSC	TCSC Location	Compensation (p.u)
23/15	778.76	903.68	Line-29	0.0270
22/9	404.43	442.65	Line-13	0.0243
22/5	255.68	271.17	Line -3	0.0849
21/6	103.98	149.33	Line-5	0.0320
18/5	255.89	272.49	Line -3	0.0833

c. Incorporation with SVC:

When one SVC is incorporated in the system, if we consider all buses of system, there are 24 possible locations for the SVC. The amount of compensation offered by SVC is 0 to 0.1 (p.u) i.e., Bsvc. After using Real Genetic Algorithm, the results obtained are shown in Table-6.

Table-6: IEEE-24 BUS Incorporation with SVC

Source bus no.	ATC without SVC	AT with SVC (M.W)	SVC Location	Compen(p.u)
23/15	778.76	865.36	Bus-8	0.0715
22/9	404.43	420.12	Bus-23	0.019
22/5	255.68	268.81	Bus-7	0.0717
21/6	103.98	128.23	Bus-6	0.0262
18/5	255.89	267.92	Bus-7	0.012

C. IEEE-75 BUS Reliability Test System

a. Without FACTS:

The Available Transfer Capability (ATC) is computed for a set of source/sink transfers using Continuous Power Flow (CPF).

Table-7 shows the ATCs for IEEE 75-bus system without FACTs device.

Table-7: IEEE-75 BUS without FACTS

Source bus no.	ATC (M.W)	Violation Constraint (Line flow/Voltage)
2/35	77.60	Line-26 overflow
3/19	195.76	Bus-17 voltage limit
5/56	41.20	Line-11overflow
8/46	128.93	Line-25 overflow
11/45	127.48	Line-26overflow

b. Incorporation with TCSC:

When TCSC is incorporated in the system, if we consider all lines of system, there are 97 possible locations for the TCSC. 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-8.

Table-8: IEEE-75 BUS with Incorporation TCSC

Source bus no.	ATC without TCSC	ATC with TCSC	TCSC Location	Compe nsation (p.u)
2/35	77.60	214.22	Line-2	0.0467
3/19	195.76	223.71	Line-27	0.0534
5/56	41.20	73.26	Line -26	0.0710
8/46	128.93	170.00	Line-14	0.0293
11/45	127.48	158.43	Line -9	0.0921

c. Incorporation with SVC:

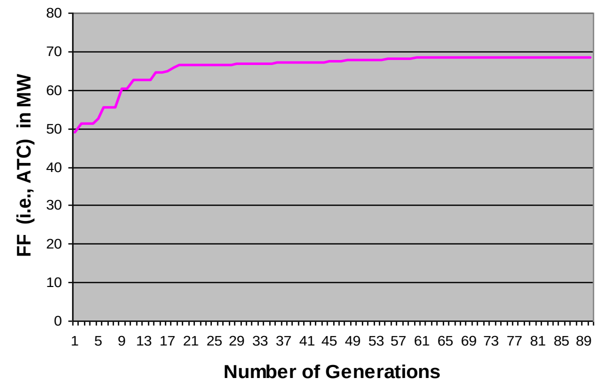
When one SVC is incorporated in the system, if we consider all buses of system, there are 75 possible locations for the SVC. The amount of compensation offered by SVC is 0 to 0.1 (p.u) i.e., Bsvc. After using Real Genetic Algorithm, the results obtained are shown in Table-9.

Table-6: IEEE-75 BUS with Incorporation SVC

Source bus no.	ATC without SVC	AT with SVC (M.W)	SVC Location	Compen (p.u)
2/35	77.60	184.21	Bus-35	0.0301
3/19	195.76	201.01	Bus-27	0.0412
5/56	41.20	51.94	Bus-29	0.0679
8/46	128.93	150.87	Bus-35	0.0214
11/45	127.48	134.84	Bus-47	0.0463

The GA parameters selected were:

- Population size = 20
- Elitism probability = 0.15
- Crossover probability = 0.60
- Mutation probability = 0.01
- Generations number = 100.



6. Conclusion

To facilitate the electricity market operation and trade, sufficient transmission capability should be provided to satisfy the demand of increasing power transactions reliably. The conflict of this requirement and the restrictions on the transmission expansion in the unbundled power industry has motivated the development of methodologies to enhance the ATC of the existing transmission grids. The ATC is computed for various transactions using Continuous Power Flow method on IEEE-14, IEEE-24&IEEE-75 reliability test system considering line thermal limit as well as bus voltage limit. The improvement of ATC using TCSC or SVC is studied and demonstrated with reliability test systems. The location and control parameter of TCSC and SVC 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 or SVC with the aim of maximizing the Available Transfer Capability. From the results, it is shown that installing SVC as a FACTS device will improve voltage profile as well as resulting ATC enhancement, where as TCSC can improve ATC in both thermal dominant case and voltage dominant case. Finally, it is clearly shows from the results that TCSC is more effective than SVC in improving ATC.

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Author's Profile

G. S. S. Manikanta has received Bachelor of Technology degree in Electrical and Electronics Engineering from Nova college of Engineering and Technology in 2012. Presently he is pursuing M. Tech in Power System Control & Automation from Sri Vasavi Engineering College, Tadepalligudem, Andhra Pradesh, India.

M. R. P. Reddy received the Bachelor of Engineering degree in Electrical &Electronics Engineering from Basaveshwar Engineering College , in 1999 and Master's degree from JNTU KAKINADA in 2007. He is pursuing Ph.D. from JNTU HYDERABAD. Currently, he is a Associate Professor at Sri Vasavi Engineering College. His areas of interests are Power Electronics and FACTS Controllers.

Ch. Rambabu received the Bachelor of Engineering degree in Electrical &Electronics Engineering from Madras University, in 2000 and Master's degree from JNTU Anantapur in 2005. He is pursuing Ph.D. from JNTU Kakinada. Currently, he is a Professor at Sri Vasavi Engineering College. His areas of interests are power system control, Optimization techniques and FACTS.