Available Transfer Capability (ATC) Enhancement of Transmission Line Using TCSC FACTS Controller

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Abstract--- **Transfer of bulk electrical power over long distance is routine in the world in order to have reliable and economical electrical supply. But the transmission system has a limited capability of transfer power. The maximum power that can be transfer is called transfer capability. To operate the power system safely and to gain the benefits of the bulk power transfers, the transfer capabilities must be calculated and the power system plant an operated, so that the power transfer do not exceed the transfer capabilities. Thus, in this paper, for further power transactions, Available Transfer Capability has calculated and also enhanced by placing TCSC FACTS controller with the methodology using Continuation Power Flow on IEEE-24 bus RTS in MATLAB.**

Keywords: Available Transfer Capability (ATC), Continuation power flow (CPF), Genetic algorithm (GA), Thyristor Control Series Compensation (TCSC)

I. INTRODUCTION

In the power system's present scenario is the power supply industries are being restructured to serve the public well. In this restructured scenario allows competition for generators and trading in the industry which can be seen as cost reduction in power production and distribution, improves efficiency and increase choices for consumer. But the user can utilizes common transmission line to transfer power from generator companies (GENCOS) to distribution companies (DISCOS) because of tight limitation in development of new facilities due to financial, ecological and social issues. Due to competition in GENCOS, it may causes frequent overloading and congestion of transmission line. In these circumstances the existing transmission facilities are exhaustively utilized which is governed by ISO.

ISO is the independent system operator who keeps eye on the transmission line activities. It also calculates power transfer capabilities of transmission line to transfer bulk amount of power which is very essential for an economic and secure power supply. The federal energy Regulatory commission (FERC) allows open access of ISO data for freedom of choice to consumer and GENCOS [1]. As discussed in report of North American Electric Reliability Council (NERC) established Available Transfer Capability (ATC) definition and determination in 1996 [3] subsequently, the ATC of transmission network required to calculate at regular instant to ensure that system is running in reliable manner while serving extensive variety of bilateral and multilateral transactions.

The ATC of a transmission network is a measure of its unutilized transfer capability available for further transactions over and above already committed uses without violating system security constraints [3]. Mathematical definition of ATC is total transfer capability (TTC) less existing benefit margin (EBM) less capacity benefit margin (CBM) less transmission reliability margin (TRM).

$$ATC = TTC - EBM - CBM - TRM$$ [3]

As per Gravener and Nwankpa, the ATC is the limiting transfer value between two control areas (source and sink) that is available without any violation of power system operating properties [20].

The accurate determination of ATC has becomes essential responsibility of the ISO and to update it continuously for market participants through open access same time information system (OASIS).

To increase in power transfer capability of existing transmission line, the new Flexible AC Transmission System technology has developed with the various type of controller without any requirement of addition new transmission line.

From the steady state power flow perspective, systems don't regularly share power in proportion to their ratings, where in most circumstances, voltage profile can't be smooth. Along these lines, ATC qualities are constantly restricted by heavily loaded bus with moderately low voltage. FACTS idea makes it conceivable to utilize circuit reactance, voltage magnitude, and phase angle as controls to redistribute line flow and regulate voltage profile.

FACTS devices can gives surety of enhancement of ATC. It is effective alternative to conventional methods. FACTS are giving new controls in both steady state power flow control as well as dynamic stability control [4].

There are three strategies to determine ATC, namely continuation power flow, optimization power flow, linear sensitivity factor based ATC [20].

The continuation power flow requires repeated solution of power flow [10]. It is the simple method to compute ATC. ATC results acquired by CPF based strategies are precise as it considers system non-linearity and control changes.

Ajjarapu.v et al. introduced a technique for finding a continuum of power flow solutions by predictor-corrector scheme with avoiding jacobian singularity by slightly

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reforming the power flow equations in 1992 [10]. Ejebe et al. introduced a novel detailing of ATC issue in light of full AC power flow solution to incorporate the impacts of reactive power flows, voltage limits as well as voltage stability and line flow limits with use of continuation power flow [5]. Ejebe et al. also introduced linear sensitivity factor based method for accurate determination of ATC [6].

In the current years in the examination field of computational intelligence Population based, search algorithms are extremely prevalent. . GA is optimization technique based on phenomenon of natural evolution which observed by Charles Darwin In which fittest survival will survive. GA has three genetic operators as selection, crossover and mutation [9]. Tjing T Lie et al. developed an algorithm for best location of FACTS devices on transmission line which leads reduction in generation cost and investment cost of FACTS devices [13]. Wang Feng et al. used Genetic Algorithm to determine location and amount of compensation given to TCSC for enhancement of Total Transfer Capability (TTC) of transmission line [17]. In the literature of T.Nireekhshana et al. describes basic advantages of installing FACTS devices such as SVC and TCSC at best location at which SVC can improve voltage profile and TCSC can improve ATC with incorporation of Real code Genetic Algorithm (RGA) [15]. Cay, L. J et al. used GA for finding optimal location of TCSC and optimal reactance of TCSC to compensate inductive reactance of line [9].

This is the analysis based paper. In this paper with incorporation of GA and continuation power flow has used to calculate ATC for IEEE24 bus reliable test system (RTS) [18]. The rest of the paper is flow as follows: Section II the Static Modelling of TCSC. Section III using Continuation Power Flow (CPF) determination of ATC. Section IV results and discussion. Finally, section V carries out commitments with conclusion.

II. STATIC MODELING OF TCSC FACTS DEVICE

In this paper, TCSC FACTS device have been used. TCSC can change line reactance as shown in figure. The power flow P_{ij} depends on voltage magnitude (V_i & V_j), phase angle (δ) difference between line connecting buses, and line reactance (X_{ij}).

$$P_{ij}=\frac{V_i V_j(\delta_i-\delta_j)}{X_{ij}} \qquad (1)$$

Power flow optimization can be done by changing line parameters. To do steady state analysis FACTS devices mathematical model developed. Transmission line reactance is modified by TCSC that is why it is modelled. To increase power flow through line, line inductive reactance is compensated by capacitive reactance of TCSC. TCSC rating is relying on the transmission line reactance [9].

Equivalent reactance of line,

$$X_{ij} = X_{line} + X_{TCSC} \qquad (2)$$

Where $X_{TCSC}=u_{TCSC}.X_{line}$ (3)

u_{TCSC} = degree of compensation.

X_{TCSC} is capacitive reactance of TCSC ($-jX_{TCSC}$) placed between bus i & j. TCSC should be working in the range of compensation 20% inductive to 70% capacitive to keep away from overcompensation. [2].

Capacitive compensation $u_{TCSC} = -0.7X_{ij}$ [12]
Inductive compensation $u_{TCSC} = 0.2X_{ij}$ [13]

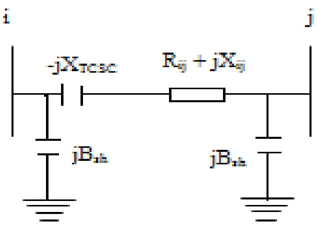

Fig.1: Functional diagram of TCSC

Line's series impedance between bus i & j [14],

$$Z_{ij} = R_{ij} + j X_{ij} = \frac{1}{G_{ij}+jB_{ij}} \qquad (4)$$

Where, G denotes Conductance &
B denotes Susceptance

The power flow through the line i-j without TCSC FACTS device [14] [9].

Active power,

$$P_{ij} = V_i^2 G_{ij} - V_i V_j \left(G_{ij}\cos\delta_{ij} + B_{ij}\sin\delta_{ij}\right) \qquad (5)$$

Reactive power,

$$Q_{ij} = V_i^2 (G_{ij}+B_{sh}) - V_i V_j \left(G_{ij}\cos\delta_{ij} - B_{ij}\sin\delta_{ij}\right) \qquad (6)$$

$$\text{Where } G_{ij} = \frac{R_{ij}}{(R_{ij}^2+X_{ij}^2)}, \; B_{ij} = \frac{-X_{ij}}{(R_{ij}^2+X_{ij}^2)} \qquad (7)$$

And with the placing TCSC FACTS device between bus i & j eq (5), (6) will be modified with

$$G_{ij} = \frac{R_{ij}}{(R_{ij}^2+(X_{ij}-X_{TCSC})^2)}, \; B_{ij} = \frac{-(X_{ij}-X_{TCSC})}{(R_{ij}^2+(X_{ij}-X_{TCSC})^2)} \qquad (8)$$

III. PROPOSED METHODOLOGY

A. *Continuation power flow (CPF)*[10]

CPF has fairly simple principle. The Solution path is found by predictor corrector scheme. CPF is the method to find intense as possible amount of a scalar parameter in linear function which is varied in sources at buses in power flow cases. CPF method adequately increases parameters step by step in series, it solve the power flow problem at every single step. Power flow solution desired for incrementing in particular direction from base case. Newton power flow method used to solve solution barrier and to fulfil requirement for Jacobian matrix at every single steps. The process last long until physical condition

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or limit restrict further increment in steps. Though voltage collapse, CPF produces solutions [2]. Without any modification, CPF is applicable to calculate ATC.

The stopping criteria of load flow are difference of specified power to calculated power should be less than epsilon (error).

To determine ATC, the injections Pi and Qi at sending end bus and receiving end bus are function of load parameter λ. Until limit reached, CPF algorithm starts from initial value and then increment in load parameter λ. Load can define as,

$$P^i_D = (1 + \lambda)\, P^i_{Do} \quad (9)$$ [2]

$$Q^i_D = (1 + \lambda)\, Q^i_{Do} \quad (10)$$ [2]

Where, Active and reactive power of bus "i" at initial point is P^i_{Do} & Q^i_{Do}

And active and reactive power of bus "i" increased by load parameter λ is P^i_D & Q^i_D.

Objective function of CPF is

$$ATC = \max (P^i_D) \quad (11)$$

Subject to, Equality constraints,

$$P_G + P_D + loss = 0$$

Where P_G = Power Generation

P_D = load demand

Inequality constraints,

Voltage limit:

$$|V_i|_{min} \leq |V_i| \leq |V_i|_{max} \qquad [0.95 \text{ p.u}, 1.15 \text{ p.u}]$$

And, Thermal limit:

$$S_{ij} < S_{ijmax}$$

Where S_{ij} = apparent power, $S_{ij\,max}$ = Thermal limit in MW.

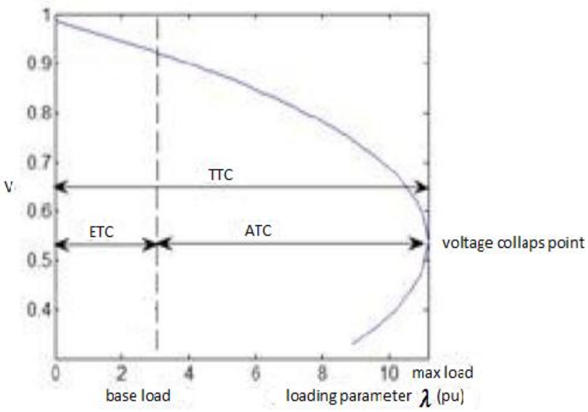

Fig.2: PV curve and ATC for calculation [11]

B. Genetic algorithm(GA)

The genetic algorithm is made by inspiration of natural evolutionary process [15]. For objective function, it do not need mathematical model [16]. Mostly evolutionary programming has been chosen for optimization of power system problems and it is fast and accurate. It has two different operator namely crossover and mutation. The aim behind applying of GA is find best location to placement of TCSC on transmission line in accordance with compensation.

GA initialized with generating 1 to 38 random integer number having population of 60. As per compensation percentage decided which is multiplied with reactance of branches and subtracted from actual reactance. Hence, the two population strings have created. The two populations are line numbers and compensative reactance is applied to CPF. Now second stage is to calculate maximization of objective function for every individual of populations which is also refer as fitness function [12]. Maximum fitness is ATC which is quality of each population solution [17].

Fitness function of GA is,

$$FF = \text{Max (ATC)} \quad (12)$$

From fitness function, the best solution has more chance to be inherited. And worse populations are discarded and by roulette wheel selection and then using crossover and mutation remaining chromosomes have created until time up or maximum iteration has defined. At the stage, the algorithm has converged, and most of the individuals in the population are generally identical, and represent a suboptimal solution to the problem [19]. GAs have convex crossover operator which is recombination of different parents chromosomes and make new child chromosome [15]. The convex crossover can be occurring with a probability close to 1.

$$X' = u_1 x + u_2 y \quad (13)$$

$$Y' = u_1 y + u_2 x \quad (14)$$

$$u_1 + u_2 = 1,\ u_1, u_2 > 0$$

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where x, y are two parents chromosomes and X', Y' are two child chromosomes. u_1, u_2 have got from random number between 0to1.

Mutation brings diversity to the population to avert immaturity convergence [15]. An arithmetic mutation operator that has demonstrated effective in various reviews is dynamic or non-uniform mutation, which is utilized as a part of this paper. At low probability, a portion of new child chromosome's some bits are flipped. This is intended for fine-tuning targeted at accomplishing a high degree of precision. For mutation, gene x_K is selected of perent x. Then the resulting gene has selected with equal probability from given choices

$$x'_k = x_k + r\,(b_k - x_k)\left(1-\frac{t}{T}\right)^b$$

or

$$x'_k = x_k + r\,(x_k - a_k)\left(1-\frac{t}{T}\right)^b$$

Where, r = uniform random number in the range of (0, 1)
t = current generation number
T = maximum generation number
b = degree of non-uniformity =2

As number of generation increases, the amount of mutation decreases.

IV. RESULTS DISCUSSION

By using IEEE-24 bus RTS [18], ATC is determined for set of transactions. The margin of ATC can be further expanded by appropriate location and control parameters of FACTS devices. In this paper, TCSC FACTS controller has selected. For ATC maximization, GA has used to find best location and control parameter of TCSC FACTS device [2]. In this paper, the whole analysis has drawn of ATC at base case.

At base case, ATC has determined for a set of different transactions with using CPF which have shown in Table 1. Also violations of thermal limit and voltage limits during power flow have shown in Table 1.

Table 1: ATC without TCSC FACTS controller

Seller Bus No.	Buyer Bus No.	ATC (p.u) without TCSC	Violation constraint (line flow/ voltage)
23	15	7.7000	Overflow line-24
10	3	2.8342	Bus-6 voltage limit
23,10	15,3	2.9000	Bus-6 voltage limit

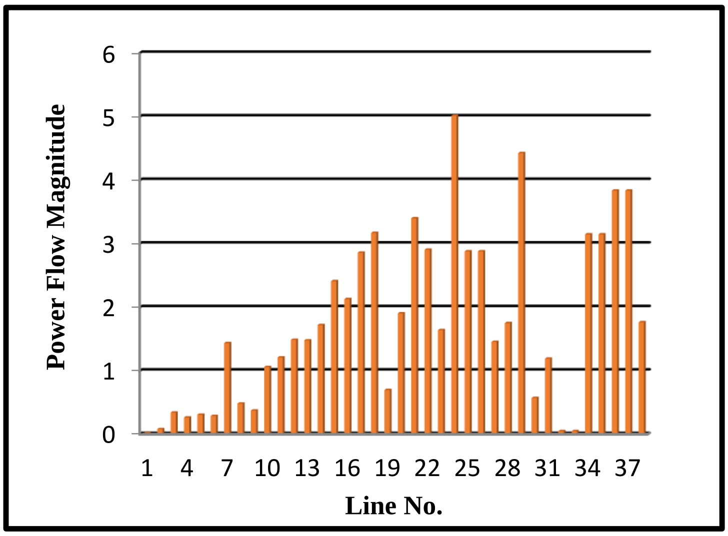

Fig.3: Power flow before placing FACTS controller

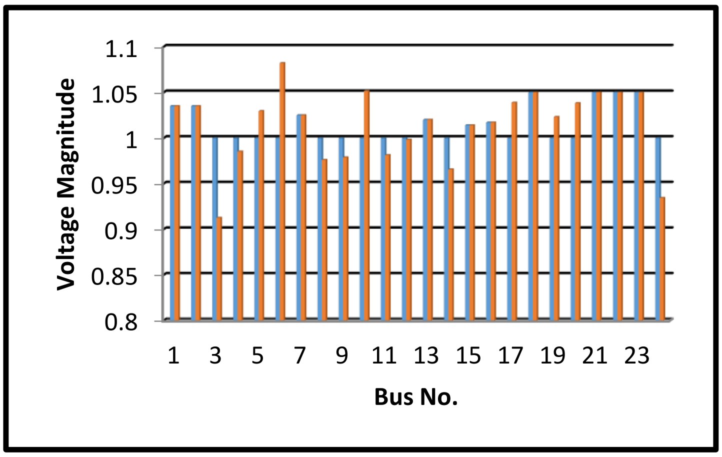

Fig.4: Bus Voltage Profile

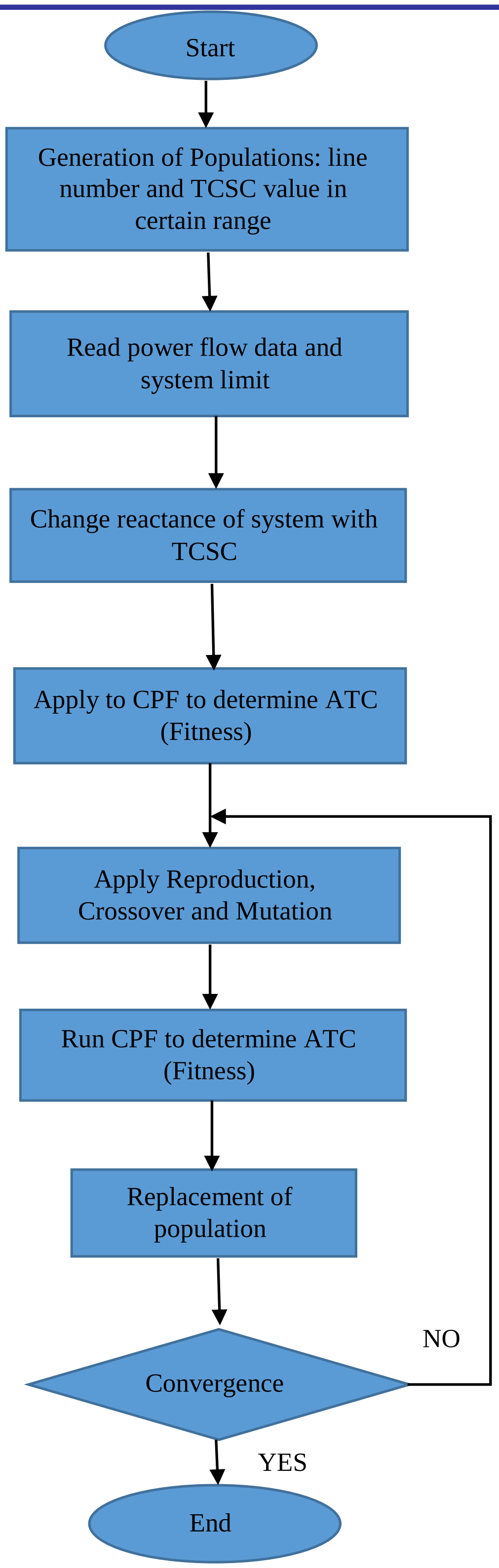

Fig.5: Flow chart of attempted methodology

Fig.3 & Fig.4 shows graphical representation of constraints has violated during CPF for single as well as multi transactions respectively. For single transaction from bus no. 23 to bus no.15, there is thermal limit of 24th line has violated which can be seen in Fig.3. For single transaction from bus no. 10 to bus no. 3 and for multi transaction from buses 23 & 10 to buses 15 & 3, there is voltage limit has violated of bus no.6 which can be seen in Fig.4.

Table.2: Determined ATC with using TCSC FACTS controller

Seller Bus No.	Buyer Bus No.	ATC (p.u) with using TCSC	TCSC Location	Violation constraint (line flow/ voltage)
23	15	7.7400	Line-23	-
10	3	2.8650	Line-7	-
23,10	15,3	2.9100	Line-7	-

After placing TCSC FACTS controller to the system, ATC has improved compared to without placing FACTS controller as well as there is all constraints are within their limits and also power transfer has increased through line due to capacitive reactance of TCSC FACTS controller introduced in series with line.

The question will arise from results that, why particular line has selected only to place FACTS controller? The answer is, after introduction of TCSC in the system, genetic algorithm leads possibility of 38 locations for placement of TCSC for IEEE-24 bus RTS. After applying GA, best location for placement of TCSC as well as best compensation value of TCSC has obtained for all different transactions from highest value of fitness function.

From the Table.2 for the given transaction, compensation has given to line reactance, ATC increases respectively as compare to ATC without FACTS device. If appropriate compensation has given to line reactance, NRLF takes long time to converge that more increment in load parameter λ. If NRLF converges fast then less increment in load parameter λ.

V. CONCLUSION

In this paper, ATC enhancement using TCSC has performed on IEEE-24 bus RTS with the methodology using continuation power flow (CPF). Using genetic algorithm (GA), best location for TCSC to be placed in system and for respective location of TCSC best compensation value could achieve, so that CPF can take more time to get converge. For the maximization of ATC, there should optimal placement of FACTS devices and their control parameters. For both thermal dominant as well as voltage dominant case, ATC can improve using TCSC.

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Appendix

GA parameters	
Population size	60
Cross over probability	0.8
mutation probability	0.05
Elitism probability	0.2
Generations number	50
Roulette wheel selection	2

Fig: 6 A Single line diagram of the IEEE 24 bus Reliability Test System [18]