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**Research Article**

# MODEING & INCORPORATION OF SVC & TCSC IN 24 BUS FOR ATC IMPROVEMENT EMPLOY REAL GENETIC ALGORITHM

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**ABSTRACT**

In this paper, the use of TCSC and SVC 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. In this thesis, ATC is computed using Continuous Power Flow (CPF) method considering both line thermal limit as well as bus voltage limits. Real-code Genetic Algorithm is used as the optimization tool to determine the location as well as the controlling parameter of TCSC or SVC simultaneously. The performance of the Real-code Genetic Algorithm has been tested on IEEE 24-Bus Reliability Test System.

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.

## INTRODUCTION

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 [10]. 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 and SVC on the ATC enhancement are studied and demonstrated through case studies. It is shown that installing SVC in the proper location will improve voltage profile as well as ATC, and TCSC will improve the ATC.[3]

The voltage fluctuations are largely a consequence of the voltage drop in series impedances of lines, transformers, and generators. Therefore, adding or subtracting the FACTS Controller voltage in series can be the most cost-effective way of improving the voltage profile. Nevertheless, a shunt controller is much more effective in maintaining a required voltage profile at a substation bus.[8] One important advantage of the shunt Controller is that it serves the bus node independently of the individual lines connected to the bus.

In a typical power system the existence of reactive power is prominent since most loads are naturally inductive. Reactive power represents energy alternately stored and released by inductors and/or capacitors. It also affects system voltages, energy loss as well as system security.

### *Overview of Available Transfer Capability*

### *Introduction*

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.

### *Transfer Capability*

Transfer capability is the measure of the ability of interconnected electric systems to *reliably* move or transfer

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power from one area to another over all transmission lines (or paths) between those areas under specified system conditions [6]. The units of transfer capability are in terms of electric power, generally expressed in megawatts (MW). In this context, “area” may be an individual electric system, power pool, control area, sub region, or North American Electric Reliability Council (NERC) Region, or a portion of any of these. Transfer capability is also directional in nature. That is, the transfer capability from Area A to Area B is *not* generally equal to the transfer capability from Area B to Area A.

### *Modeling of TCSC and SVC*

### *Introduction*

In this chapter, different types of FACTs devices and their importance have been discussed. The equivalent circuit and modeling of TCSC and SVC are discussed in detail.

### *Basic types of Facts Devices*

In general, FACTS controllers can be divided into four categories:

1. Series Controllers
2. Shunt Controllers
3. Combined Series-Series Controllers
4. Combined Series-Shunt Controllers

### *Benefits of Utilizing 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 transmission system reliability and availability as FACTS devices mitigate the effects of faults and make supply of electricity more securely by reducing the number of trips. 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. There is an increased quality of supply for sensitive industries because FACTS devices can provide the required quality of supply to high quality electricity supply where loss of supply or voltage dips leading to interruptions in manufacturing processes resulting in high economic loss could be overcome. Furthermore FACTS provide in terms of environmental benefits as they do not contain harmful materials nor produce waste or pollutants. In fact FACTS devices help to distribute electricity more economically through better utilization of existing installations thereby reducing the need for additional transmission lines [2].

### *Series Compensation*

### *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.

### *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 [11]. Fig. 1 shows a transmission line incorporating a TCSC.

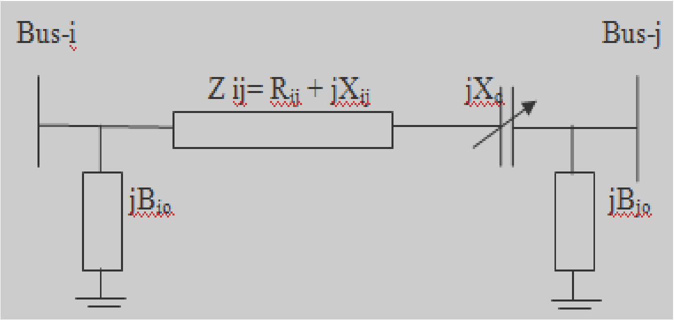

**Fig 1** Equivalent circuit of a line with TCSC

Where $X_{ij}$ is the reactance of the line, $R_{ij}$ *is* the resistance of the line, $B_{io}$ and $B_{jo}$ 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:

$$\Delta y_{ij} = y'_{ij} - y_{ij} = (g'_{ij} + jb'_{ij}) - (g_{ij} + jb_{ij}) \tag{1}$$

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

$$g'_{ij} = \frac{r_{ij}}{\sqrt{r_{ij}^{2} + (x_{ij} + x_c)^2}}, \; b'_{ij} = -\frac{x_{ij} + x_c}{\sqrt{r_{ij}^{2} + (x_{ij} + x_c)^2}} \tag{3}$$

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 [11]:

$$Y'_{bus} = Y_{bus} + \begin{array}{cl} \left[\begin{array}{ccccccc} 0 & 0 & 0 & \cdots & 0 & 0 & 0 \\ 0 & \Delta y_{ij} & 0 & \cdots & 0 & -\Delta y_{ij} & 0 \\ 0 & 0 & 0 & \cdots & 0 & 0 & 0 \\ \cdots & \cdots & \cdots & \cdots & 0 & \cdots & 0 \\ 0 & 0 & 0 & \cdots & 0 & 0 & 0 \\ 0 & -\Delta y_{ij} & 0 & \cdots & 0 & \Delta y_{ij} & 0 \\ 0 & 0 & 0 & \cdots & 0 & 0 & 0 \end{array}\right] & \begin{array}{l} \\ row-i \\ \\ \\ \\ row-j \\ \\ \end{array} \\ \begin{array}{ccccccc} & col-i & & & & col-j & \end{array} & \end{array} \tag{4}$$

### *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 $X_c$, 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. (5) [13].

$$K_s = \frac{Xc}{Xij} \tag{5}$$

Science the objective is to determine the amount of series capacitor on the line; it will therefore be useful to define the degree of compensation (Ks) in the total line impedance, which is

$$Z = R_{ij} + j\,[X_{ij}\,(1-K_s)] \qquad (6)$$

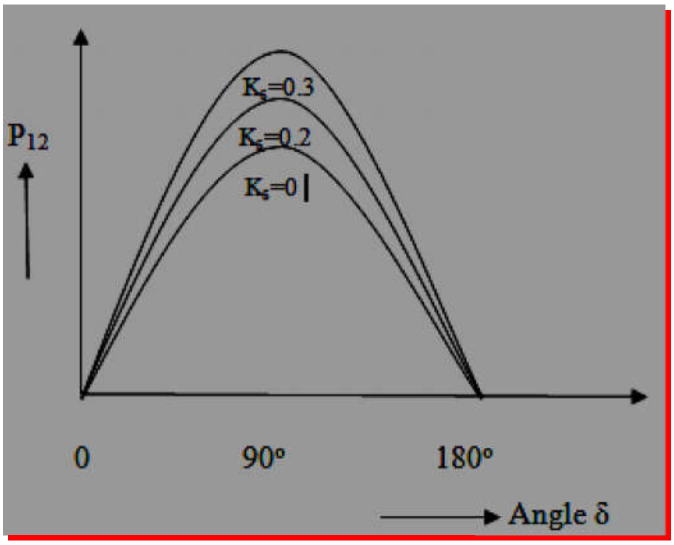

**Fig 2** power angle Vs real power flow

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. From the Eqn. (6), it is concluded that the total line impedance is in reactive nature and is function if control parameter $K_s$ i.e., degree of series compensation. From Eqn. (1) the real power as function of Ks and it can be varied from 0 to 40% as shown in fig. 2 [13].

$$P_{12} = \frac{V_1 V_2}{X_{12}(1-K_s)} \sin\theta_{12} \qquad (7)$$

### *Drawback of Series Compensation*

One major drawback with the series capacitor compensation is that special protective devices are required to protect the capacitors and bypass the high current produced when a short circuit occurs. Also, the inclusion of the series capacitors establishes a resonant circuit that can oscillate at a frequency below the normal sub-synchronous frequency when stimulated by a disturbance. This phenomenon is referred to as sub-synchronous resonance (SSR).

### *Algorithm for Newton Raphson power flow Using TCSC*

a. Read the system line data, bus data and TCSC data
   ***Line data****:* From bus, to bus, line resistance, line reactance, half-line charging susceptance and off nominal tap ratio.
   ***Bus data****:* Bus no, Bus itype, $P_{gen}$, $Q_{gen}$, $P_{load}$, $Q_{load}$, and shunt capacitor data.
   ***TCSC data****:* TCSC Line no., variable reactance ($X_C$)
b. Form $Y_{bus}$ using sparsity technique.
c. Modify the $Y_{bus}$ elements with the value of TCSC reactance.

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

$$\Delta y_{ij} = y'_{ij} - y_{ij} = (g'_{ij} + jb'_{ij}) - (g_{ij} + jb_{ij})$$

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

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

Modification in diagonal elements as

$$Y_{pp}(i) = Y_{pp}(i) + \Delta y_{ij}$$

$$Y_{pp}(j) = Y_{pp}(j) + \Delta y_{ij}$$

Modification in off-diagonal elements as

$$yline(ij) = yline(ij) - \Delta y_{ij}$$

a. $k_1$=1 iteration count
b. Set $|\Delta P_{\max}|$=0.0 , $|\Delta Q_{\max}|$=0.0
c. Cal $P_{shed}(i)$,$Q_{shed}(i)$, for i=1 to n.
   Where $P_{shed}(i) = P_{gen}(i) - P_{load}(i)$
   $Q_{shed}(i) = Q_{gen}(i) - Q_{load}(i)$
d. Calculate $P_{cal}(i)=\sum_{q=1}^{n} |V_i||V_q||Y_{iq}|\cos(\delta_{iq}-\theta_{iq})$
   $Q_{cal}(i)=\sum_{q=1}^{n} |V_i||V_q||Y_{iq}|\sin(\delta_{iq}-\theta_{iq})$
e. Calculate $\Delta P(i)=P_{shed}(i) - P_{cal}(i)$
   $\Delta Q(i)=Q_{shed}(i) - Q_{cal}(i)$ for i=1 to n
   Set $\Delta P_{slack}$=0.0, $\Delta Q_{slack}$=0.0,
f. Calculate $|\Delta P_{\max}|$ and $|\Delta Q_{\max}|$ form [ Δ p] and [ Δ Q] vectors
g. Is $|\Delta P_{\max}| \leq \in$ and $|\Delta Q_{\max}| \leq \in$

If yes, go to step no. 6

Form Jacobian elements

1. Initialize A[i][j]=0.0 for i=1 to 2n , j=1 to 2n
2. Form diagonal elements $H_{pp}$, $N_{pp}$, $M_{pp}$ & $L_{pp}$
3. Form off – diagonal elements: $H_{pq}$, $N_{pq}$, $M_{pq}$ & $L_{pp}$
4. Form right hand side vector (mismatch vector)

B[i]= Δ P[i] , B[i+n]= Δ Q[i] for i=1 to n
Modify the elements
For p=slack bus; $H_{pp}$=1e20=$10^{20}$; $L_{pp}$=1e20=$10^{20}$;

Use Gauss – Elimination method for following
[A] [ Δ X] = [B]
Update the phase angle and voltage magnitudes i=1 to n
For itype=1 &2, calculate $\delta_i = \delta_i + \Delta X_i$ & $V_i=V_i+\{\Delta X_{(i+n)}\}V_i$

One iteration over
Advance iteration count $k_1=k_1+1$

If ($k_1$< itermax) then goto step 2(b) else print problem is not converged in
"itermax" iterations, Stop.

Print problem is converged in 'iter'no. of iterations.

a. Calculate line flows
b. Bus powers, Slack bus power.

c. Print the converged voltages, line flows and powers.

### *Shunt Compensation*

### *Introduction*

Static shunt compensation is used to influence the natural electrical characteristics of the transmission line to increase the steady-state transmittable power and to control the voltage profile along the line. In principle, all shunt-type controllers inject additional current into the system at the point of common coupling (PCC) through the means of a voltage source converter. The impedance of the shunt controller, which is connected to the line voltage, causes a variable current flow, and hence represents an injection of current into the line. The ultimate objective of applying reactive shunt compensation in a transmission system is to increase the transmittable power capability from the generator to the load, which is required to improve the steady-state transmission characteristic as well as the stability of the system [13].

### *Modeling of SVC*

The shunt compensator SVC is simply a static capacitor/reactor with susceptance $B_{svc}$ [12]. Fig. 3 shows the equivalent circuit of the SVC can be modeled as a shunt-connected variable susceptance $B_{SVC}$ at bus-i.

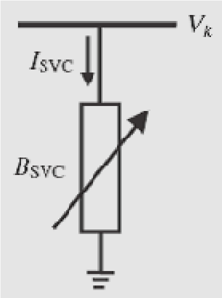

**Fig 3** Variable shunt susceptance

The reactive power injected into the bus due to SVC can be expressed as

$$Q_{svc} = B_{svc} V^2 \tag{8}$$

Where V is the voltage magnitude of the bus at which the SVC is connected. Fig. 4 shows the steady-state and dynamic voltage-current characteristics of the SVC portion of the system. In the active control range, current/susceptance and reactive power is varied to regulate voltage according to a slope (droop) characteristic. The slope value depends on the desired voltage regulation, the desired sharing of reactive power production between various sources, and other needs of the system. The slope is typically 1-5%. 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.

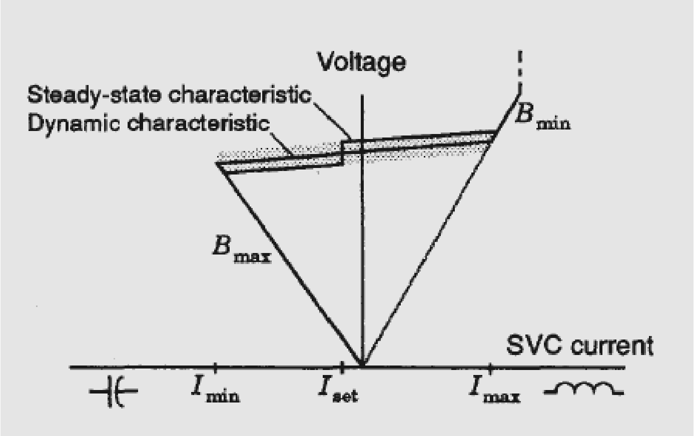

**Fig 4** SVC static characteristics at high voltage bus

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

For constant active power flow and supply voltage of $V_{rms}$, the required capacitive VAr is the difference between the pre compensation VAr and the required compensated VAr as given by equation [14]:

VAr (capacitive) =VAr (required)  VAr (Uncompensated) (3.11)

The amount of the capacitive susceptance $B_{cap}$ is then given by Eqn. (9):

$$B_{cap} = \frac{\text{VAr(Required) - VAr(Uncompensated)}}{\text{V}_{\text{rms}}^2}$$

Siemens (9)

From which the required capacitance value in Farad is given by using equation

$$\text{C (Farad)} = \frac{Bcap}{(2\pi f)} \tag{10}$$

### *Degree of Shunt Compensation ($K_d$)*

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

$$K_d = \frac{B}{\text{Im}\{y\}^l} \tag{11}$$

$K_d$ is defined as the fraction of the total inductive susceptance of shunt compensation (B) and the total charging susceptance of line $\text{Im}\{y\}^l$ [13].

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.

### *Algorithm for Newton Raphson power flow Using SVC*

a. Read the system line data, bus data and SVC data
   ***Line data:*** From bus, to bus, line resistance, line reactance, half-line charging Susceptance and off nominal tap ratio.
   ***Bus data:*** Bus no, Bus itype, $P_{gen}$, $Q_{gen}$, $P_{load}$, $Q_{load}$, and Shunt capacitor data.
   ***SVC data:*** SVC Bus no., variable susceptance ($B_{svc}$)
b. Form $Y_{bus}$ using sparsity technique.
c. Modify the $Y_{bus}$ elements with the value of SVC reactance.

When SVC is placed at ith bus, the modification in diagonal element as $Y_{pp}(i) = Y_{pp}(i) + y_{shunt}$

a. $k_1$=1 iteration count
b. Set $|\Delta P_{\max}|$=0.0, $|\Delta Q_{\max}|$=0.0
c. Cal $P_{shed}(i)$,$Q_{shed}(i)$, for i=1 to n.
   Where $P_{shed}(i) = P_{gen}(i)- P_{load}(i)$
   $Q_{shed}(i) = Q_{gen}(i)- Q_{load}(i)$
d. Calculate $P_{cal}(i)=\sum_{q=1}^{n}|V_i||V_q||Y_{iq}|\cos(\delta_{iq}-\theta_{iq})$

   $Q_{cal}(i)=\sum_{q=1}^{n}|V_i||V_q||Y_{iq}|\sin(\delta_{iq}-\theta_{iq})$
e. Calculate $\Delta P(i)=P_{shed}(i) – P_{cal}(i)$
   $\Delta Q(i)=Q_{shed}(i) - Q_{cal}(i)$ for i=1 to n
   Set $\Delta P_{slack}=0.0$, $\Delta Q_{slack}=0.0$,
f. Calculate $|\Delta P_{\max}|$ and $|\Delta Q_{\max}|$ form [Δp] and [ΔQ] vectors
g. Is $|\Delta P_{\max}| \le \in$ and $|\Delta Q_{\max}| \le \in$

If yes, go to step no. 6

Form Jacobian elements:

a. Initialize A[i][j]=0.0 for i=1 to 2n , j=1 to 2n
b. Form diagonal elements $H_{pp}$, $N_{pp}$, $M_{pp}$ & $L_{pp}$
c. Form off – diagonal elements: $H_{pq}$, $N_{pq}$, $M_{pq}$ & $L_{pp}$
d. Form right hand side vector (mismatch vector)
   B[i]= ΔP[i] , B[i+n]= ΔQ[i] for i=1 to n
e. Modify the elements
   For p=slack bus; $H_{pp}=1e20=10^{20}$; $L_{pp}=1e20=10^{20}$;

Use Gauss – Elimination method for following
[A] [ΔX] = [B]

Update the phase angle and voltage magnitudes i=1 to n
For itype=1 &2, calculate $\delta_i = \delta_i + \Delta X_i$ & $V_i=V_i+\{\Delta X_{(i+n)}\}V_i$

One iteration over

Advance iteration count $k_1=k_1+1$ If ($k_1$< itermax) then goto step 2(b) else print problem is not converged in

“itermax” iterations, Stop.

Print problem is converged in ‘iter’no. of iterations.

a. Calculate line flows
b. Bus powers, Slack bus power.
c. Print the converged voltages, line flows and powers.

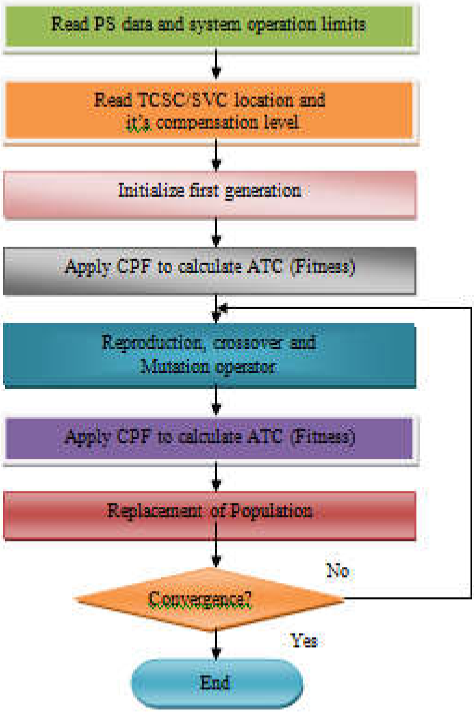

**Fig 5** RGA flow chart

### *RGA for enhancement of ATC using FACTs Device*

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 turns ratio, maximum line flow.
   ***Bus data**:* Bus no, Bus type, $P_{gen}$, $Q_{gen}$, $P_{load}$, $Q_{load}$, $P_{min}$, $P_{max}$,$V_{sp}$ Shunt capacitor data.
c. Read data for genetic operations i.e population size, elitism probability cross-over probability, mutation probability
d. Read no. of control variables i.e. TCSC/SVC location and reactance/susceptance
e. Read maximum line flow limits, load bus voltage limits.
f. Read the sending bus (seller bus) *m* and the receiving bus (buyer bus) *n*.
g. Calculate $P_{shed}(i)$, $Q_{shed}(i)$, for i=1 to no. of buses
   Where $P_{shed}(i)=P_{gen}(i)-P_{load}(i)$
   $Q_{shed}(i)=Q_{gen}(i)-Q_{load}(i)$
h. Form $Y_{bus}$ using sparsity technique
1. E=complex ($V_{sp}$,0)
2. Generate population size of chromosomes randomly
3. gen=1, generation count
4. (a) k1=1, chromosome count
   (b)Using the line no./bus no. and reactance/ susceptance information modify Ybus
1. Calculate ATC using NR repeated power flow
2. Calculate fitness (k1) = ATC (i.e. maximization)
3. If (k1< population size)

   k1=k1+1
   go to (iv)(b) Else go to (vii)

(i) 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)

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

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

(iv) 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. $\lambda_1$ and $\lambda_2$ is obtained by a uniform random number generator between the range (0~l).

$$x' = \lambda_1 x + \lambda_2 y$$

$$y' = \lambda_1 y + \lambda_2 x$$

$$\lambda_1 + \lambda_2 = 1,$$

$$\lambda_1, \lambda_2 > 0$$

(v) Perform mutation i.e.
If ($r_1$<Pm) perform mutation to inject new information using the following equation, where $r_1$ is a random number between 0 and 1, and Pm is the mutation probability. Finally, replace old population by new population.

$$x_k' = x_k + r(b_k - x_k)(1 - \frac{t}{T})^b \text{ or}$$

$$x_k' = x_k - r(x_k - a_k)(1 - \frac{t}{T})^b$$

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

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

## CASE STUDIES AND DISCUSSION

### *IEEE 24-bus Reliability Test System*

### *Without line outage case*

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

**Table 1** shows the ATCs for IEEE 24-bus system without FACTs device.

| Source/Sink bus no. | ATC (M.W) | Violation Constraint (Line flow/Voltage) |
|---|---|---|
| 23/15 | 770.0 | Line-24 overflow |
| 22/9 | 395.0 | Line-38 overflow |
| 22/5 | 260.0 | Line-38 overflow |
| 21/6 | 105.0 | Line-10 overflow |
| 18/5 | 260.0 | Line-38 overflow |

**Table 2** ATC without FACTS Device

| Source /Sink bus no. | ATC without TCSC (M.W) | ATC with TCSC (M.W) | TCSC Location | Compensation (p.u) |
|---|---|---|---|---|
| 23/15 | 770.0 | 810.0 | Line-28 | -0.0103 |
| 22/9 | 395.0 | 420.0 | Line-12 | -0.0635 |
| 22/5 | 260.0 | 270.0 | Line -15 | -0.0239 |
| 21/6 | 105.0 | 120.0 | Line -5 | -0.0669 |
| 18/5 | 260.0 | 270.0 | Line -15 | -0.0283 |

Table 2 ATCs after incorporating TCSC

When one TCSC is incorporated in the system, if we consider all lines of system, there are 38 possible locations for the TCSC. The location code region are set as 38 integers as 1 to 38. 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-2. It shows that with the flow control function TCSC increased the ATC significantly

### *Incorporation of 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 location code region are set as 24 integers as 1 to 24. The amount of compensation offered by SVC is 0 to 0.1 (p.u) i.e., $B_{svc}$. After using Real Genetic Algorithm, the results obtained are shown in Table-3. It shows that with the flow control function SVC increased the ATC significantly.

**Table 3** ATCs after incorporating SVC

| Source /Sink bus no. | ATC without SVC (M.W) | ATC with SVC (M.W) | SVC Location | Compensation (p.u) |
|---|---|---|---|---|
| 23/15 | 770.0 | 790.0 | Bus-20 | 0.099 |
| 22/9 | 395.0 | 405.0 | Bus-5 | 0.086 |
| 22/5 | 260.0 | 265.0 | Bus-11 | 0.081 |
| 21/6 | 105.0 | 110.0 | Bus-11 | 0.082 |
| 18/5 | 260.0 | 262.0 | Bus-5 | 0.091 |

### *With line outage*

The Available Transfer Capability (ATC) are computed for a set of source/sink transfers using Continuous Power Flow (CPF), when line-8 is physically removed from the system that is connected between bus-4 and bus-9. Fig. 5: Shows a graph voltage profile for the IEEE 24-bus system with and without outage cases.

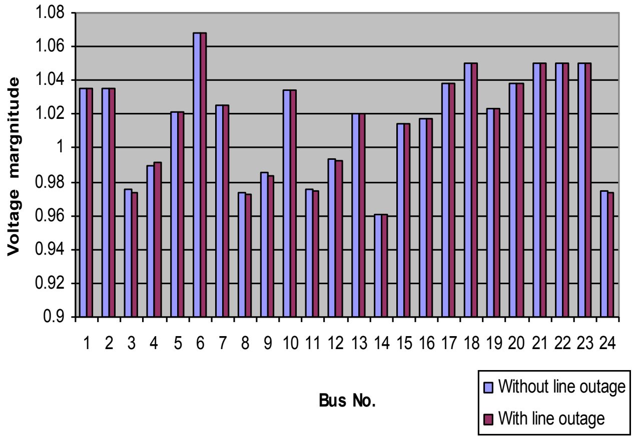

**Fig 6** Bus voltage profile for without and with line outage cases

**Table 5** Shows the ATCs for IEEE 24-bus system without FACTs device, when line-8 is physically removed.

| Source/Sink bus no. | ATC (M.W) | Violation Constraint (Line flow/Voltage) |
|---|---|---|
| 23/15 | 765.00 | Line-24 overflow |
| 22/9 | 385.00 | Bus-9 voltage limit |
| 22/5 | 214.20 | Line-9 overflow |
| 21/6 | 86.70 | Line-10 overflow |
| 18/5 | 214.20 | Line-9 overflow |

Table-5.: ATCs without FACTS Device during Line-8 outage

### *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-8. 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-6. It shows that with the flow control function TCSC increased the ATC significantly even under line outage.

**Table 6** ATCs after incorporating TCSC during line-8 outage

| Source/ Sink bus no. | ATC without TCSC (M.W) | ATC with TCSC (M.W) | TCSC Location | Compensation (p.u) |
|---|---|---|---|---|
| 23/15 | 765.00 | 801.20 | Line-25 | -0.0101 |
| 22/9 | 385.00 | 413.10 | Line-14 | -0.0652 |
| 22/5 | 214.20 | 229.50 | Line -2 | -0.0304 |
| 21/6 | 86.70 | 91.80 | Line -7 | -0.0730 |
| 18/5 | 214.20 | 229.50 | Line -2 | -0.0328 |

### *Incorporation of 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 location code region are set as 24 integers as 1 to 24. The amount of compensation offered by SVC is 0 to 0.1 (p.u) i.e., $B_{svc}$. After using Real Genetic Algorithm, the results obtained are shown in Table-7. It shows that with the flow control function SVC increased the ATC significantly during line-8 outage.

**Table 7** ATCs after incorporating SVC during line-8 outage

| Source /Sink bus no. | ATC without SVC (M.W) | ATC with SVC (M.W) | SVC Location | Compensation (p.u) |
|---|---|---|---|---|
| 23/15 | 765.00 | 785.40 | Bus-10 | 0.084 |
| 22/9 | 385.00 | 392.70 | Bus-23 | 0.099 |
| 22/5 | 214.20 | 219.30 | Bus-14 | 0.092 |
| 21/6 | 86.70 | 88.20 | Bus-6 | 0.081 |
| 18/5 | 214.20 | 224.40 | Bus-16 | 0.098 |

### *IEEE 24 bus reliability test system*

No. of buses: 24
No. of lines: 38
No. of generators: 11

**Table 8** Bus data

| Bus | Type | $P_{gen}$ | $P_{load}$ | $Q_{gen}$ | $Q_{load}$ | $V_{specified}$ | $Y_{shunt}$ |
|---|---|---|---|---|---|---|---|
| 1 | P-V | 1.52 | 1.08 | 0 | 0.22 | 1.035 | 0 |
| 2 | P-V | 1.52 | 0.97 | 0 | 0.2 | 1.035 | 0 |
| 3 | P-Q | 0 | 1.8 | 0 | 0.37 | 1 | 0 |
| 4 | P-Q | 0 | 0.74 | 0 | 0.15 | 1 | 0 |
| 5 | P-Q | 0 | 0.71 | 0 | 0.14 | 1 | 0 |
| 6 | P-Q | 0 | 1.36 | 0 | 0.28 | 1 | 0 |
| 7 | P-V | 0.04 | 1.25 | 0 | 0.25 | 1.025 | 0 |
| 8 | P-Q | 0 | 1.71 | 0 | 0.35 | 1 | 0 |
| 9 | P-Q | 0 | 1.75 | 0 | 0.36 | 1 | 0 |
| 10 | P-Q | 0 | 1.95 | 0 | 0.4 | 1 | 0 |
| 11 | P-Q | 0 | 0 | 0 | 0 | 1 | 0 |
| 12 | P-Q | 0 | 0 | 0 | 0 | 1 | 0 |
| 13 | Slack | 0 | 0 | 0 | 0 | 1.02 | 0 |
| 14 | P-V | 0 | 0.94 | 0 | 1.39 | 1 | 0 |
| 15 | P-V | 1.55 | 3.17 | 0 | 0.64 | 1.014 | 0 |
| 16 | P-V | 1.55 | 1 | 0 | 0.2 | 1.017 | 0 |
| 17 | P-Q | 0 | 0 | 0 | 0 | 1 | 0 |
| 18 | P-V | 4 | 3.33 | 0 | 0.68 | 1.05 | 0 |
| 19 | P-Q | 0 | 1.81 | 0 | 0.37 | 1 | 0 |
| 20 | P-Q | 0 | 1.28 | 0 | 0.26 | 1 | 0 |
| 21 | P-V | 4 | 0 | 0 | 0 | 1.05 | 0 |
| 22 | P-V | 3 | 0 | 0 | 0 | 1.05 | 0 |
| 23 | P-V | 6.6 | 0 | 0 | 0 | 1.05 | 0 |
| 24 | P-Q | 0 | 0 | 0 | 0 | 1 | 0 |

**Table 9** Line data

| Line | From bus | To bus | R (p.u) | X (p.u) | Half line charging Susceptance | Tap ratio | Line Rating (MVA) |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 2 | 0.0026 | 0.0139 | 0.23055 | 1 | 1.75 |
| 2 | 1 | 3 | 0.0546 | 0.2112 | 0.0286 | 1 | 1.75 |
| 3 | 1 | 5 | 0.0218 | 0.0845 | 0.01145 | 1 | 1.75 |
| 4 | 2 | 4 | 0.0328 | 0.1267 | 0.01715 | 1 | 1.75 |
| 5 | 2 | 6 | 0.0497 | 0.192 | 0.026 | 1 | 1.75 |
| 6 | 3 | 9 | 0.0308 | 0.119 | 0.0161 | 1.015 | 4 |
| 7 | 3 | 24 | 0.0023 | 0.0839 | 0 | 1 | 1.75 |
| 8 | 4 | 9 | 0.0268 | 0.1037 | 0.01405 | 1 | 1.75 |
| 9 | 5 | 10 | 0.0228 | 0.0883 | 0.01195 | 1 | 1.75 |
| 10 | 6 | 10 | 0.0139 | 0.0605 | 1.2295 | 1 | 1.75 |
| 11 | 7 | 8 | 0.0159 | 0.0614 | 0.0083 | 1 | 1.75 |
| 12 | 8 | 9 | 0.0427 | 0.1651 | 0.02235 | 1 | 1.75 |
| 13 | 8 | 10 | 0.0427 | 0.1651 | 0.02235 | 1.03 | 4.0 |
| 14 | 9 | 11 | 0.0023 | 0.0839 | 0 | 1.03 | 4.0 |
| 15 | 9 | 12 | 0.0023 | 0.0839 | 0 | 1.015 | 4.0 |
| 16 | 10 | 11 | 0.0023 | 0.0839 | 0 | 1.015 | 4.0 |
| 17 | 10 | 12 | 0.0023 | 0.0839 | 0 | 1 | 5.0 |
| 18 | 11 | 13 | 0.0061 | 0.0476 | 0.04995 | 1 | 5.0 |
| 19 | 11 | 14 | 0.0054 | 0.0418 | 0.04395 | 1 | 5.0 |
| 20 | 12 | 13 | 0.0061 | 0.0476 | 0.04995 | 1 | 5.0 |
| 21 | 12 | 23 | 0.0124 | 0.0966 | 0.1015 | 1 | 5.0 |
| 22 | 13 | 23 | 0.0111 | 0.0865 | 0.0909 | 1 | 5.0 |
| 23 | 14 | 16 | 0.005 | 0.0389 | 0.0409 | 1 | 5.0 |
| 24 | 15 | 16 | 0.0022 | 0.0173 | 0.0182 | 1 | 5.0 |
| 25 | 15 | 21 | 0.0063 | 0.049 | 0.0515 | 1 | 5.0 |
| 26 | 15 | 21 | 0.0063 | 0.049 | 0.0515 | 1 | 5.0 |
| 27 | 15 | 24 | 0.0067 | 0.0519 | 0.05455 | 1 | 5.0 |
| 28 | 16 | 17 | 0.0033 | 0.0259 | 0.02725 | 1 | 5.0 |
| 29 | 16 | 19 | 0.003 | 0.0231 | 0.02425 | 1 | 5.0 |
| 30 | 17 | 18 | 0.0018 | 0.0144 | 0.01515 | 1 | 5.0 |
| 31 | 17 | 22 | 0.0135 | 0.1053 | 0.1106 | 1 | 5.0 |
| 32 | 18 | 21 | 0.0033 | 0.0259 | 0.02725 | 1 | 5.0 |
| 33 | 18 | 21 | 0.0033 | 0.0259 | 0.02725 | 1 | 5.0 |
| 34 | 19 | 20 | 0.0051 | 0.0396 | 0.04165 | 1 | 5.0 |
| 35 | 19 | 20 | 0.0051 | 0.0396 | 0.04165 | 1 | 5.0 |
| 36 | 20 | 23 | 0.0028 | 0.0216 | 0.02275 | 1 | 5.0 |
| 37 | 20 | 23 | 0.0028 | 0.0216 | 0.02275 | 1 | 5.0 |
| 38 | 21 | 22 | 0.0087 | 0.0678 | 0.0712 | 1 | 5.0 |

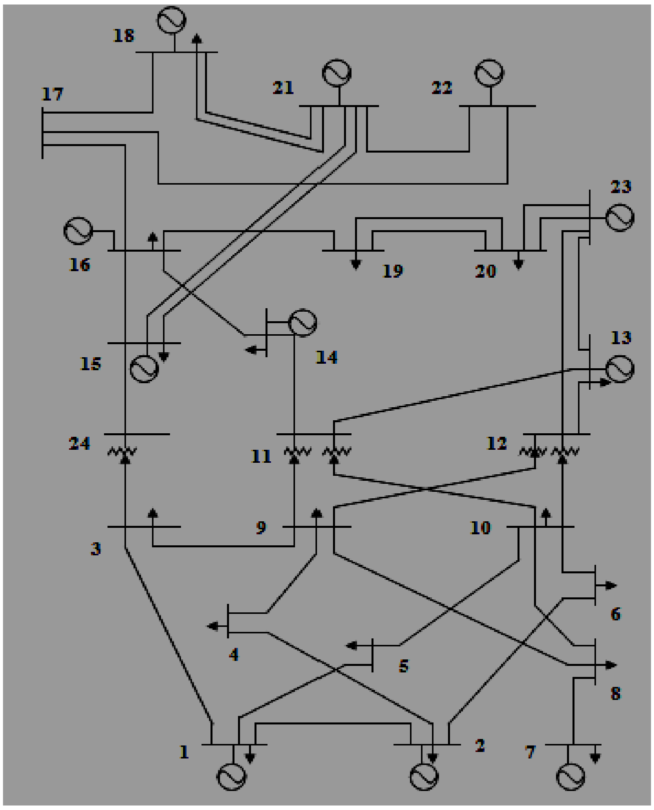

**Fig 6** 24 bus system

## CONCLUSION

ACTS 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. The combination of the series and shunt Controllers can provide the best of both, i.e. an effective power/current flow and line voltage control. For the combination of series and shunt Controllers, the shunt Controller can be a single unit serving in coordination with individual line controllers. This arrangement can provide additional benefits with unified controllers.

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