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# LOCATION OF SERIES FACTS DEVICE USING GENETIC ALGORITHM AND ENHANCEMENT OF STABILITY USING SELF-TUNING THYRISTOR CONTROLLED SERIES COMPENSATOR

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## ABSTRACT

In recent years, continuous and reliable electric energy supply is the objective of any power system operation. Over last decade FACTS devices have become popular and are very effective solution for many power system transmission problems. FACTS controllers can be used for steady state voltage regulation and control, steady state control of power flow on a transmission line, transient stability enhancement. Along with this, it also reduces the problem of sub synchronous resonance. In this regard, Flexible Alternative Current Transmission Systems (FACTS) devices play a key role in enhancing controllability and increasing power transfer capability of the network. Thyristor Controlled Series Compensator (TCSC) is an emerging FACTS device designated to achieve this objective. The location of FACTS device plays a very important role. In this paper, Genetic algorithm is used in finding optimal location of TCSC. The TCSC consists of two SCR's connected back to back which needs to be tuned properly at instants of faults or changes in load condition. Inorder to enhance stability the TCSC should be tuned properly. A self-tuning TCSC control scheme is proposed in this paper. An IEEE 5 bus system is considered to test credibility of the proposed method and the results thus obtained are subjected to analysis to determine the optimal location and also enhancement of stability.

**KEYWORDS:** Flexible Alternative Current Transmission Systems, (FACTS), Genetic Algorithm (GA), Thyristor Controlled Series Compensator (TCSC), Self Tuning Thyristor Controlled Series Compensator

## I. INTRODUCTION

The inherent power system limits restrict the power transaction which leads to the underutilization of the existing transmission resources. Traditionally, fixed or mechanically switched shunt and series capacitors, reactors and synchronous generators were being used to solve much of the problem. However, there are restrictions as to the use of these conventional devices. Desired performance was not being able to achieve effectively. Wear and tear in the mechanical components and slow response were the heart of the problems. There was a greater need for the alternative technology made of solid state devices with fast response characteristics. The need was further fuelled by worldwide restructuring of electric utilities, increasing environmental and efficiency regulations and difficulty in getting permit and right of way for the construction of overhead transmission lines. The amount of electric power, which can be transmitted between two locations through a transmission network, is limited by security and stability constraints. Power flow in the lines and transformers should not be allowed to increase to a level where a random event could cause the network collapse because of angular instability, voltage instability or cascaded outages [1].

Economic operation of power system along with the assurance of refined quality of power supply to consumers is a challenging task. Due to the introduction of deregulation in electricity market, installation of FACTS devices has become inevitable. Because of the economic considerations; installation of FACTS controllers in all the buses or the lines in a system is not feasible. There are several sensitivity based methods described for finding optimal location of FACTS devices in power systems [4]. However, it is required to find the optimal location of FACTS devices by heuristic method to overcome both economical & technical barriers in accomplishing the objective. The thyristor controlled series compensator (TCSC) can be used to rapidly modulate the effective reactance of a suitable transmission line, resulting in an improvement of the system performance. One way to limit the effects of dramatic process variations is to use an adaptive control scheme [11]. Use of Thyristor Controlled Series Compensator (TCSC) which is Flexible AC Transmission System (FACTS) device gives a number of benefits for the user of the grid, all contributing to increase the power transmission capability of new as well as existing transmission lines. These benefits include improvement in system stability, voltage regulation, reactive power balance, load sharing between parallel lines and reduction in transmission losses [2]. Optimal location of TCSC is a task assigned to Genetic Algorithm (GA) where GA is an approach to find optimal solutions for search problems through application of the principles of evolutionary biology.

The optimal location of series FACTS device and series – shunt FACTS device to relieve congestion in the 57- bus system is used [7]. Different operating conditions can be simulated for determination of the optimal FACTS location[10] and also the compensation rate of TCSC can be considered for running GA program [9]. Sometimes one part of the power system needs to be switched on and off due to technical reasons. In these instances the circuit breaker needs to be operated. When the circuit breaker is operated the switching frequency causes the power system's parameters to get distorted. The voltage will be unregulated which may lead to disturb the stability of the system. This needs to be taken care and the system should be brought to stability. This paper is focused on optimal location of TCSC using GA. This paper also focuses on a self-tuning TCSC which controls the thyristor's present in the TCSC by proper firing the SCRs at appropriate firing angle. An overview of modeling of TCSC is presented in section II. Brief description of genetic algorithm is presented in section III. Optimal location of TCSC using genetic algorithm is shown in section IV, along with simulation results, which elaborates the traits of an IEEE 5-bus system under consideration. Section VI presents a SIMULINK model of a 5 bus system with and without TCSC along with results of simulation. Section VII presents conclusions.

## II. THYRISTOR CONTROLLED SERIES COMPENSATOR (TCSC) MODELING

The IEEETCSC-a capacitive reactance compensator, which consists of three main components: capacitor bank *C*, bypass inductor *L* and bidirectional thyristors SCR1 and SCR2 [4]. Series capacitive compensation is used to increase line power transfer as well as to enhance system stability. Figure 1 shows the main circuit of a *TCSC*.

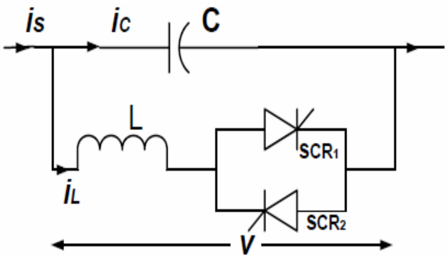

**Figure 1: Configuration of a TCSC**

The firing angles of the thyristors are controlled to adjust the *TCSC* reactance according to the system control algorithm, normally in response to some system parameter variations. According to the variation of the thyristorfiring angle, this process can be modeled as a fast switch between corresponding reactance offered to the power system. Assuming that the total current passing through the *TCSC* is sinusoidal, the equivalent reactance at the fundamental frequency can be represented as a variable reactance $X_{TCSC}$.

The *TCSC* can be controlled to work either in the capacitive or the inductive zones avoiding steady state resonance [4]. There exists a steady-state relationship between the firing angle α and the reactance $X_{TCSC}$, as described by the following equation [4]:

$$X_{TCSC}\ (\alpha) = \frac{X_C\, X_l\,(\alpha)}{X_l\,(\alpha) - X_C} \tag{1}$$

Where,

$$X_l\,(\alpha) = X_L \frac{\pi}{\pi - 2\alpha - \sin\alpha} \tag{2}$$

Where, $\alpha$ is the firing angle, *XL* is the reactance of inductor and *Xl*is the effective reactance of inductor at firing angle [4].

A model of transmission line with a TCSC connected between bus-i and bus-j is shown in Figure 2. During steady state, the TCSC can be considered as a static reactance –jxc. The controllable reactance xc is directly used as acontrol variable in the power flow equations.

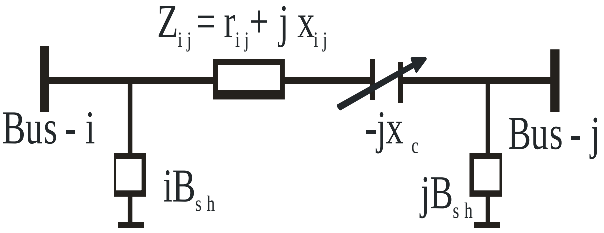

**Figure 2(a): TCSC Model**

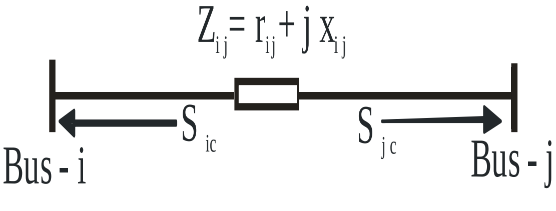

**Figure 2(b): Injection Model of TCSC**

The real power injections at bus-i($P_{ic}$) and bus-j($p_{jc}$) are given by the following equations[2]:

$$P_{ic}=V^2_i\,\Delta G_{ij} - V_iVj[\Delta G_{ij}\cos\delta_{ij} + \Delta B_{ij}\sin\delta_{ij}] \tag{3}$$

$$P_{jc}=V^2_j\,\Delta G_{ij} - V_iVj[\Delta G_{ij}\cos\delta_{ij} - \Delta B_{ij}\sin\delta_{ij}] \tag{4}$$

Similarly, the reactive power injections at bus-i ($Q_{ic}$) and bus- j ($Q_{jc}$) can be expressed as:

$$Q_{ic}= - V^2_i \Delta B_{ij} - V_i Vj[\Delta G_{ij} \sin\delta_{ij} - \Delta B_{ij} \cos\delta_{ij}] \quad (5)$$

$$Q_{jc}= -V^2_j \Delta B_{ij} + V_i Vj[\Delta G_{ij} \sin\delta_{ij} + \Delta B_{ij} \cos\delta_{ij}] \quad (6)$$

Where

$$\Delta G_{ij} = \frac{x_c r_{ij} (x_c - 2x_{ij})}{\left(r_{ij}^2 + x_{ij}^2\right)\left(r_{ij}^2 + \left(x_{ij} - x_c\right)^2\right)} \quad (7)$$

$$\Delta B_{ij} = \frac{-x_c \left(r_{ij}^2 - x_{ij}^2 + x_c x_{ij}\right)}{\left(r_{ij}^2 + x_{ij}^2\right)\left(r_{ij}^2 + \left(x_{ij} - x_c\right)^2\right)} \quad (8)$$

Where $\Delta G_{ij}$ and$\Delta B_{ij}$ are the changes in conductance and susceptance of the line i-j respectively.

This model of TCSC is used to properly modify the parameters of transmission lines with TCSC for optimal location.

## III. LOCATION OF TCSC

### A. Genetic Algorithm

Conventional methods in solving power system design, planning, operation and control problems have been extensively used for different applications. But these methods suffer from several difficulties due to necessities of derivative existence, providing suboptimal solutions, etc. In this regard, Computational intelligence (CI) methods can give better solution in several conditions and are being widely applied in the electrical engineering applications. CI is a modern tool for solving complex problems which are difficult to be solved by the conventional techniques in power system domain. Heuristic optimization techniques are general purpose methods that are very flexible and can be applied to many types of objective functions and constraints. In this paper, ***Genetic algorithm (GA)***, a main paradigm of evolutionary strategy, is applied for the optimal location of FACTS.

A typical genetic algorithm requires:

- A genetic representation of the solution domain
- A fitness function to evaluate the solution domain.

GAs are global search techniques based on the mechanism of natural selection and genetics[8]

A standard representation of the solution is as an array of bits. The main property that makes these genetic representations convenient is that their parts are easily aligned due to their fixed size, which facilitates simple crossover operations. Variable length representations may also be used, but crossover implementation is more complex in this case.

To perform its optimization-like process, the GA employs three operators to propagate its population from one generation to another. The first operator is the “Selection” operator that mimics the principal of “Survival of the Fittest”. The second operator is the “Crossover” operator, which mimics mating in biological populations. The crossover operator propagates features of good surviving designs from the current population into the future population, which will have better fitness value on average. The last operator is “Mutation”, which promotes diversity in population characteristics.

The mutation operator allows for global search of the design space and prevents the algorithm from getting trapped in local minima.

The fitness function is defined over the genetic representation and measures the *quality* of the represented solution [4]. The fitness function is always problem dependent. Fitness function is the function that assigns fitness value to each individual. For minimization problem fitness function is an equivalent maximization problem chosen such that the optimum point remains unchanged, fitness function for loss minimization problem can be expressed as

Fitness function = 1/ objective fuction+1.

It is easy to find the maximum value of objective function using GA, the inverse function is selected to convert the objective function into a maximum one. Figure 3 shows the flow chart of GA.

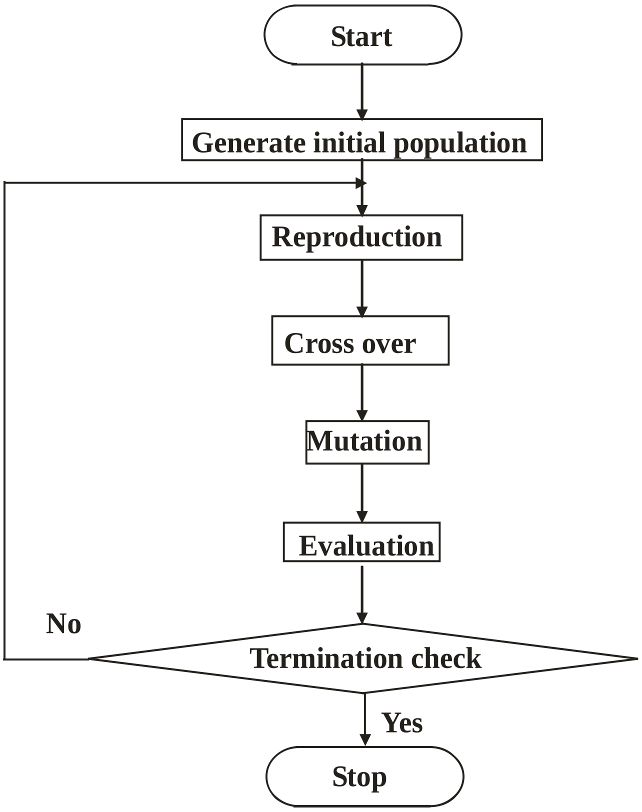

**Figure 3: Flow Chart of Genetic Algorithm**

### B. Problem Formulation Equations

Equations that are considered for optimization to reduce the losses

$$P_{loss}( i ) = P_{loss}( i ) + real ( conj (( V_m ( n ) * V_m ( l ) ) ) * Ybus (n, l) * base\ mva ) ); \quad (9)$$

$$P_{loss}(l) = \frac{1}{sum(P_{loss})} + 1 \quad (10)$$

n = number of buses

$V_m$ = Voltage magnitude of the nth bus

l = line data

$$P_{gi} - P_{di} = \sum_{j=1}^{n} |V_i||V_j||Y_{ij}| \cos(\delta_i - \delta_j - \theta_{ij}) \quad (11)$$

$$Q_{gi} - Q_{di} = \sum_{j=1}^{n} |V_i||V_j||Y_{ij}| \sin(\delta_i - \delta_j - \theta_{ij}) \quad (12)$$

$$P_{gi,\min} \le P_{gi} \le P_{gi,\max}$$

$$Q_{gi,\min} \le Q_{gi} \le Q_{gi,\max} \quad (13)$$

$$P_{di,\min} \le P_{di} \le P_{di,\max}$$

$$Q_{di,\min} \le Q_{di} \le Q_{di,\max} \quad (14)$$

$$V_{i,\min} \le V_i \le V_{i,\max} \quad (15)$$

$P_{Gi}$,$Q_{Gi}$arethe realandreactivepowergenerationat busi.$P_{di}$,$Q_{di}$aretherealandreactivepowerdemandsatbus i.

$V_i$,$\delta_i$ arevoltage andanglesatbusi.

$P_{gi,\ min}$, $P_{gi,max}$realpowerminimumandmaximum generationlimitsatbusi.

$Q_{gi,\ min}$, $Q_{gi,max}$reactive powerminimumand maximum generationlimitsatbusi.

$P_{di,\ min}$, $P_{di,max}$realpowerminimumandmaximumdemand limitsatbusi.

$Q_{di,\ min}$,$Q_{di,max}$reactive powerminimum andmaximum demandlimitsatbusi.

### C. Proposed Algorithm for Location of TCSC

The steps to locate optimally a TCSC with Genetic Algorithm are as follows:

**STEP 1:** Read system data.

**STEP 2:** Run load flow to find losses using Newton Raphsonmethod.

**STEP 3:** Assume suitable population size, say 100.

**STEP 4:** Generate initial population.

**STEP 5:** Set counter=0.

**STEP 6:** Randomly generate chromosomes (Parameter$x_{TCSC}$).

**STEP 7:** Modify admittance matrix with the help of randomlygenerated $x_{tcsc}$ values.

**STEP 8:** Run load flow with modified admittance matrix calculated losses and evaluate fitness valuei.e, $P_{loss}$

**STEP 9:** Increment counterfunction.

**STEP 10:** Select new population using roulette wheel selection criterion.

**STEP 11:** Perform crossover, mutation (if any) and evaluate objective function.

**STEP 12:** Add off- springs generated by cross over and mutations to the population generated by selection and replace initial population.

**STEP 13:** Repeat the process until minimum loss is reachedwhich shows that convergence is achieved.

**STEP 14:** Place the TCSC in the line where minimum loss is obtained.

## IV. SIMULATION RESULTS

### A. Case Study

An IEEE 5-bus system is taken as a test system. Single line diagram of this system is shown in Figure 4. The data of the system is given in Appendix- A. The system consists of 5 buses, 7 branches and 3 generators connected to bus 1, 2 & 3 [12].

The range of TCSC is taken as -0.8% to +0.2% of the line reactance and the power flow is carried out before & after placing the TCSC to determine their benefits.

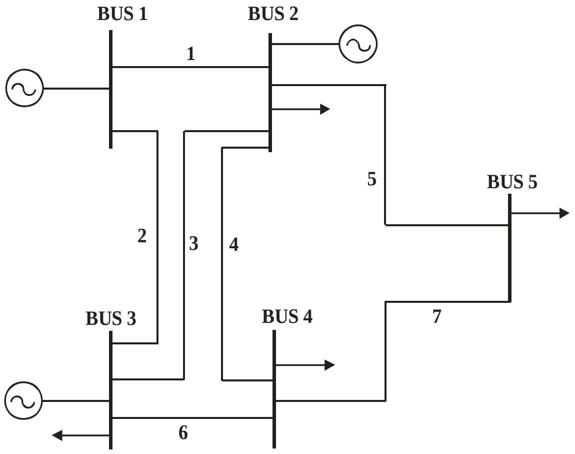

**Figure 4: Single Line Diagram of 5 Bus System**

### B. Load Flow Analysis of 5-Bus System

Load flow analysis has been carried out for IEEE 5 – bus system using MIPOWER and MATLAB software and the results are tabulated in Table 1.

**Table 1: Line Flow Analysis of an IEEE 5 Bus System without TCSC**

| Parameter | Matlab |
|---|---|
| P loss in MW | 3.055 |
| Q loss in MVAr | -26.14 |
| Total loss | 30.8677 |
| MW load | 150 |
| MVAR load | 95 |
| Pg | 153.05 |
| Qg | 73.23 |
| δ 2 | -1.782 |
| δ 3 | -2.664 |
| δ 4 | -3.243 |
| δ 5 | -4.405 |
| V4 | 1.019 |
| V5 | 0.99 |

### C. Placing of TCSC for Each Line

TCSC has been placed for all the seven branches one at a time and the obtained results have been tabulated in Table 2.

**Table 2: Line Flow with TCSC for Each Line**

| Branch No | Line | $X_L$ before Placing TCSC | $X_{total}$ after Placing TCSC | $P_{loss}$ Total in MW | $P_g$ Total in MW | $Q_g$ Total | Iteration Convergence |
|---|---|---|---|---|---|---|---|
| 6 | 3-4 | 0.03 | 0.0109 | 8.70955 | 158.692 | 92.670 | 8th |
| 1 | 1-2 | 0.06 | 0.0403 | 8.71065 | 158.711 | 92.674 | 1st |
| 5 | 2-5 | 0.12 | 0.0622 | 8.71065 | 158.711 | 92.674 | 1st |
| 2 | 1-3 | 0.24 | 0.2437 | 8.71065 | 158.711 | 92.674 | 1st |
| 3 | 2-3 | 0.18 | 0.1537 | 8.71065 | 158.711 | 92.674 | 1st |
| 4 | 2-4 | 0.18 | 0.1388 | 8.71065 | 158.711 | 92.674 | 1st |
| 7 | 4-5 | 0.24 | 0.119 | 8.42563 | 158.43 | 78.462 | 4th |

From Table 2 it is inferred that

- Total Power loss varies.
- Total generated real and reactive power increases..
- $X_{TCSC}$ varies from -0.05 to + 0.004.

### D. Optimal Location of TCSC Determined by the GA Method

Proposed GA methodology has been applied to the IEEE 5 bus system. In this paper,reactance of TCSC has been considered as chromosomes. The GA parameters are given in Table 4.

From the simulation results it can be inferred that TCSC has been optimally located in one of the seven branches where minimum loss occurs. The location of TCSC and the corresponding reactance with GA are tabulated in Table 3.

**Table 3: Reactance Values with TCSC Using GA**

| Line | Branch | | $X_{old}$ | X Added |
|---|---|---|---|---|
| | From Node | To Node | | |
| 1 | 1 | 2 | 0.06 | 0.000 |
| 2 | 1 | 3 | 0.24 | 0.000 |
| 3 | 2 | 3 | 0.18 | 0.000 |
| 4 | 2 | 4 | 0.18 | 0.000 |
| 5 | 2 | 5 | 0.12 | 0.000 |
| 6 | 3 | 4 | 0.03 | -0.0191345 |
| 7 | 4 | 5 | 0.24 | 0.000 |

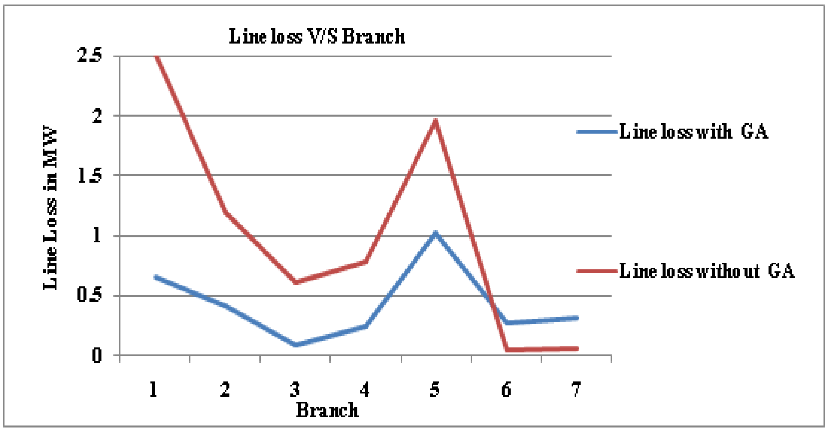

Figure 5: Line Loss verses Branch

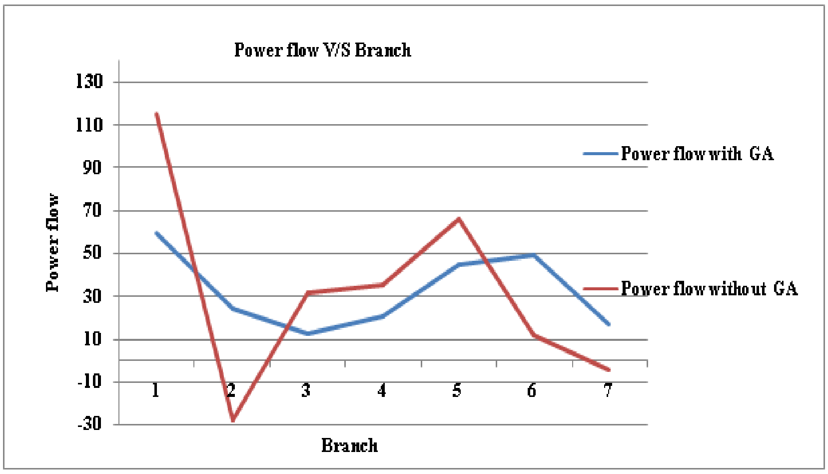

Figure 6: Power Flow verses Branch

**Table 4: GA Parameters**

| |
|---|
| Population size =100 |
| Cross over rate = 0.8 |
| Mutation rate = 0.02 |
| Convergence iteration = 8 |
| Maximum iteration = 120 |
| Selection = Roulette wheel |

The following are the benefits observed by placing TCSC in the 6th branch by genetic algorithm method into the system.

- Reduction of total real power loss from3.055MW to 1.3290 MW.
- Increase of real power generation from 153.05 MW to 158.711MW
- Increase of reactive power generation from 73.23 MVAr to 78.62MVAr.
- Graph of line loss verses branch shown in Figure 5.
- Graph of power flow verses branch shown in Figure 6.

### E. Summary of the Results

**Table 5: Result Summary**

| Parameter | Without GA | Proposed GA |
|---|---|---|
| Line flow 3-4 | 43.573 MW | 47.336 MW |
| Total loss | 3.055MW | 1.32 MW |
| Line reactance 6th Branch, line 3-4 | Before | After |
|  | $X_l$=0.03 | $X_{eff}=X_l+X_{TCSC}$=0.0109 |

Degree of compensation = 40%.

## V. SIMULINK MODEL OF IEEE 5-BUS SYSTEM BEFORE AND AFTER TCSC

### A. Simulink Model of 5 Bus IEEE System before Location of TCSC

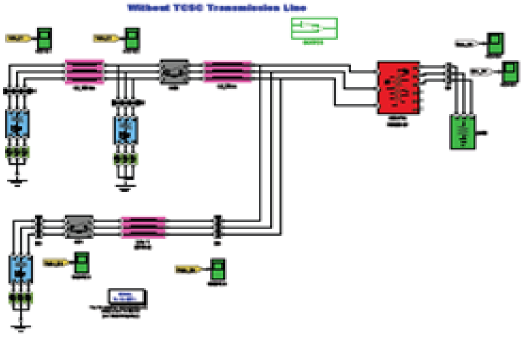

Figure 7: Simulink Model of IEEE 5-Bus System

### B. Simulink Model of 5 Bus IEEE System after Location of TCSC

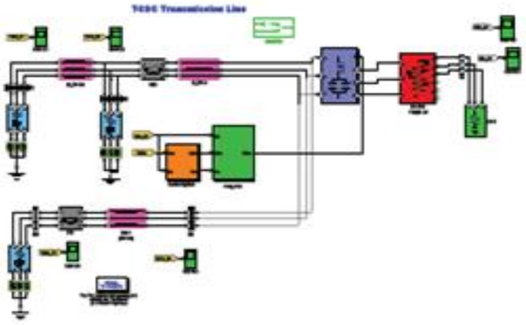

Figure 8: Simulink Model of 5-Bus System with TCSC

### C. Results before Placing TCSC

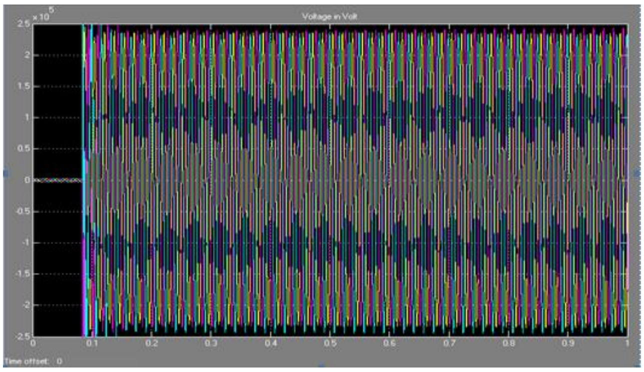

Figure 9: Voltage Waveform

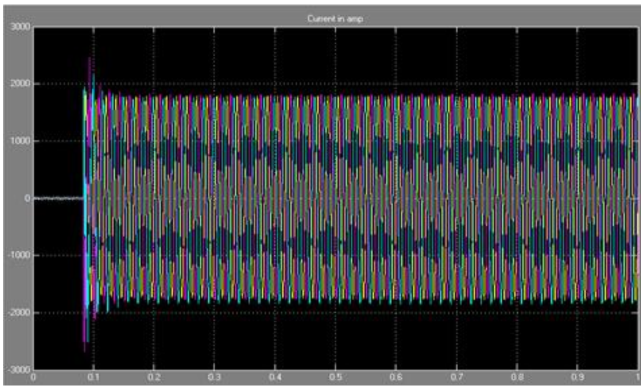

Figure 10: Current Waveform

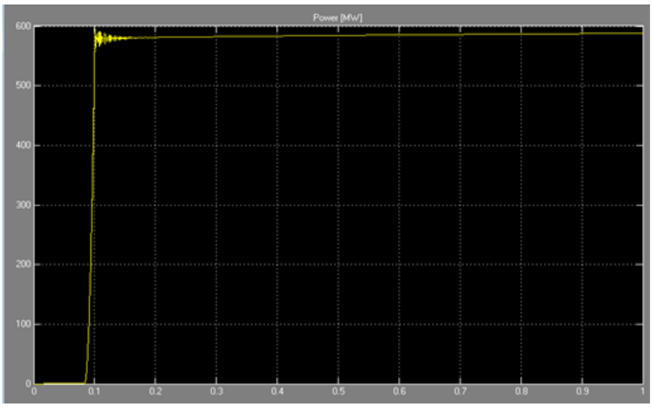

Figure 11: Power Output

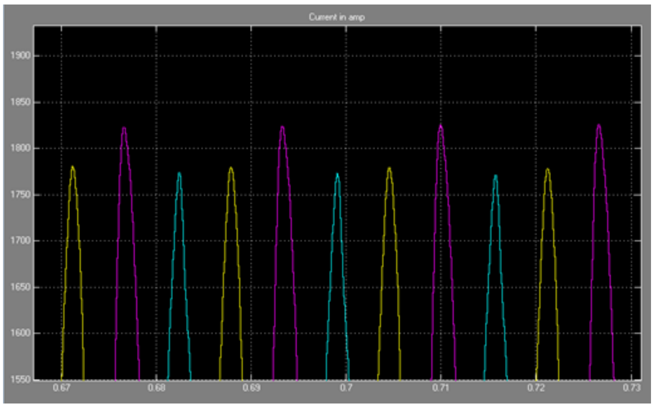

Figure 12: Unregulated Current

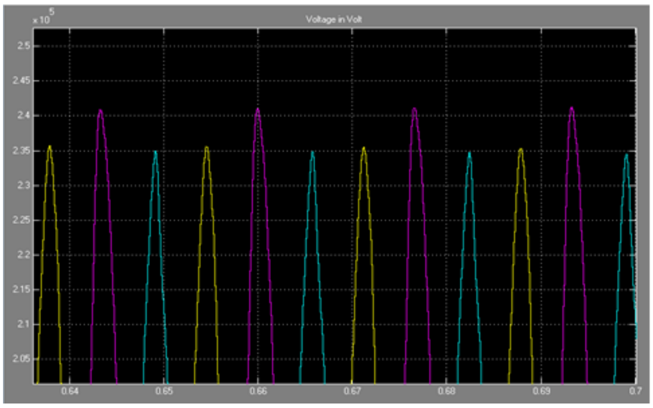

Figure 13: Unregulated Voltage

## D. RESULTS OF PLACING TCSC IN THE SELECTED LINE USING GA

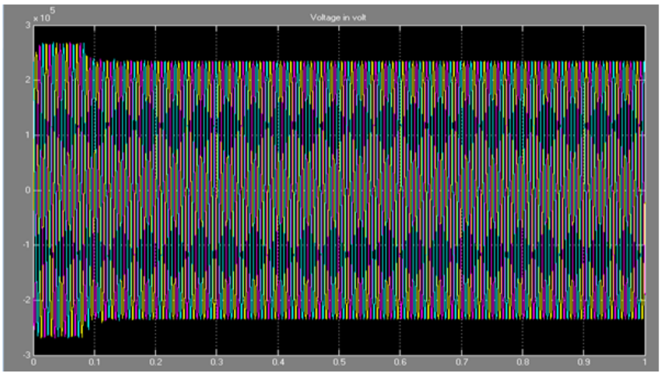

Figure 14: Voltage Waveform

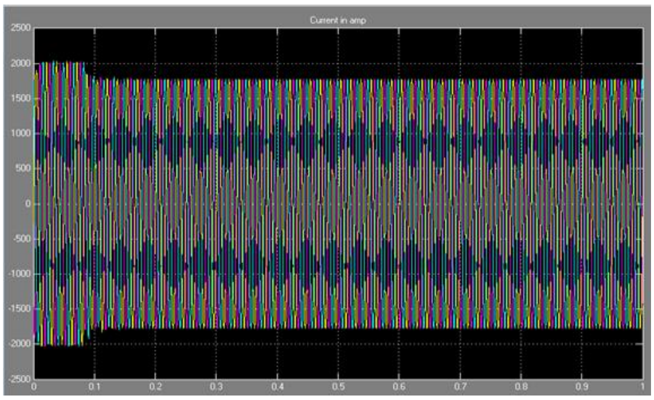

Figure 15: Current Waveform

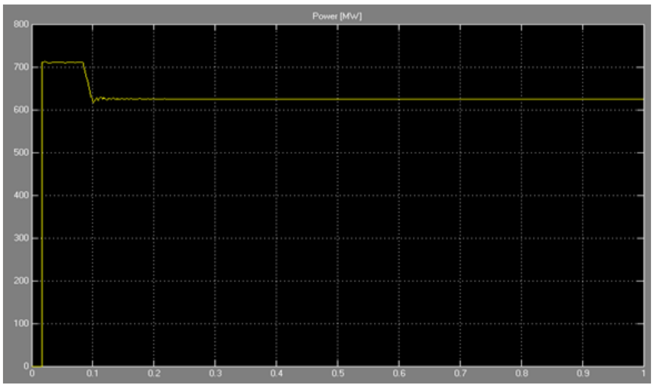

Figure 16: Power Waveform

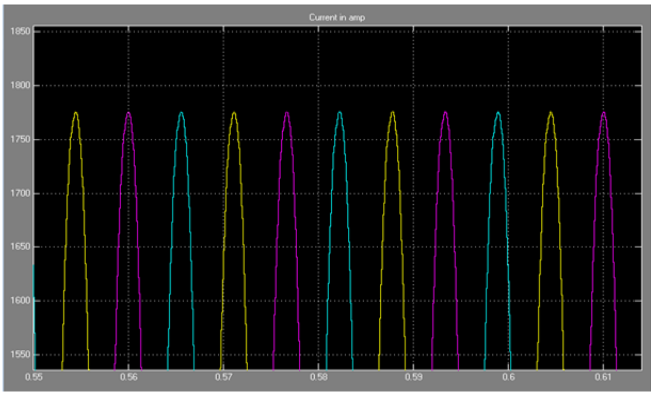

Figure 17: Regulated Current Waveform

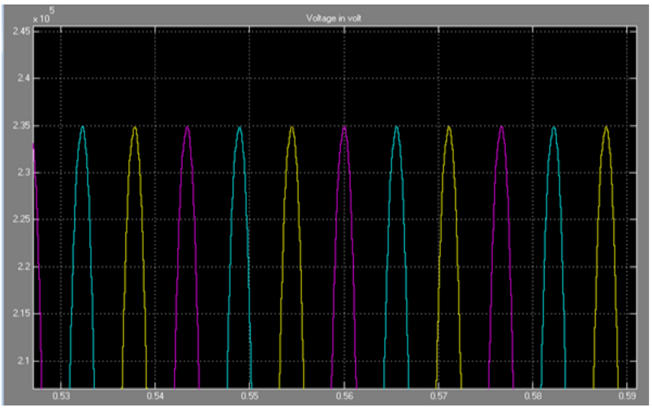

Figure 18: Regulated Voltage and Power

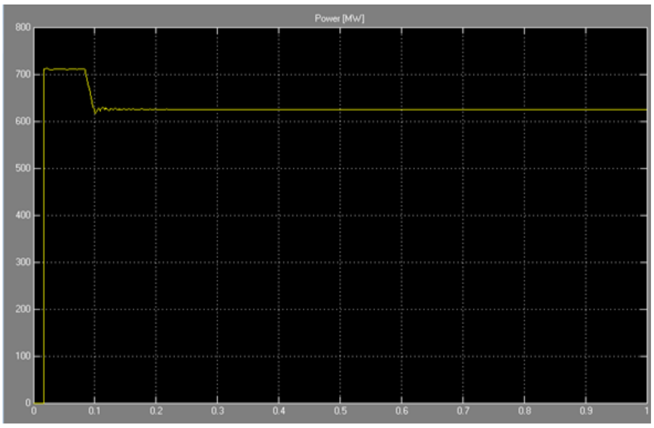

Figure 19

## VI. CONCLUSIONS

It has been observed from the result that, by using Genetic Algorithm method, TCSC could be optimally placed in the branch 6 with 40% degree of compensation. The effect of placing TCSC in branch 6 resulted in loss reduction in the lines. The total loss effectively reduced from 3.0556MW to 1.32 MW resulting in a loss reduction of 43.2% and it increases the power transfer capability of the line. After obtaining the optimal location of TCSC the stability of the system can be increased by including a self tuning TCSC. It can be observed from the waveforms that the thedistorsions in the voltage, current and power waveforms due to switching of circuit breakers are effectively smoothed using the TCSC. This is a suitable method to stabilize a system. It can be extended to check the fault clearing time also. Hence this method can be easily extended to practical systems with more number of buses.

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## APPENDICES

$S_{base}$ = 100 MVA

$V_{base}$ = 220KV

$V_{max}$ = 1.06 p.u

$V_{min}$ = 1 p.u

$P_{max}$ gen. at bus 1= 85MW

$P_{max}$gen. at bus 2= 80MW

$P_{max}$gen. at bus 3= 70MW

$P_{min}$ gen.= 10 MW for all generators

$Q_{max}$ gen. at bus 1=50 MVAr

$Q_{max}$ gen. at bus 2= 50MVAr

$Q_{max}$ gen. at bus 3= 40 MVAr

$Q_{min}$ gen = 100MVAr for all generators.