# Implementation of Genetic Algorithm for Optimal Power Flow with Thyristor-controlled series compensator

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**Abstract**: Finding the Optimal power flow for a multi-bus power system with a TCSC is crucial for reducing system costs while maximising performance. To identify the best solution in such systems, a genetic algorithm (GA) should be implemented with multi objective function by including minimization of losses, fuel consumption, and increase the system performance. The fuel consumption parameter and optimal power flow settings needs to be obtained by basic optimal power flow solution under various operating conditions in multi bus system. Both active power losses and reactive power compensation are taken into consideration by the objective function. An effective GA is used to evaluate the IEEE 30 and 75 bus system in order to find the best power flow when employing TCSC. This report presents MATLAB-based data to verify the suggested strategy.

Keywords: Thyristor-controlled series compensator (TCSC), GA, Optimal power flow, 75-Bus IEEE system.

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## 1. INTRODUCTION

A power transfer system is necessary equipment for efficient power transmission using the FACTS. These FACTS (Flexible AC Transmission System) devices are playing a vital role in transmitting maximum power with minimum cost. These also can help in the operation to be more flexible and secure. Further, these are having ability to operate the system more efficient under various operating conditions. Connecting FACTS devices at the proper position helps lower the overall cost of electricity transmission. Typically, these depend on electronic equipment with regulated power.
Generally adding an extra FACTS device to the power system is an economical aspect. However, it can add some benefits in flexibility of power flow at the expense of the cost. Therefore, identification of proper location for installing a new FACTS device is very important to make cost effective system. This procedure required a pre planned simulation to analyze the responses. One of the greatest techniques is the examination of the ideal power flow. A TCSC is one of many FACTS gadgets that is frequently employed due to its ease of usage and low investment cost. Usually power system transmission is a multi bus system. A 30 and 75 bus systems are more popular in India. Hence it is very difficult to identify proper location for installing a FACTS device.

Optimization algorithms will help to solve complex functions in efficient manner and can get fast response even under involvement of multi objective functions. A simple and efficient algorithm for identifying best placement in power system is Genetic Algorithm (GA). Hence, in this paper a GA is developed for 30 and 75 IEEE buses for optimal power flow using TCSC.

This paper is organized by including modeling of FACTS devices in Section-II. The formation of problem is presented in Section-III. A detailed solution with GA is Explains in Section-IV. Results and discussions are given in Section-V. The research conclusion provided in Section-VI and references are arranged at the end of the paper.

## 2. MODELING OF TCSC

A simple layout of TCSC installation on transmission bus system is depicted in Fig. 1. This is installed in between buses i,j. The transmission system between these two buses having an impedance of Zij, hence the TCSC needs to be minimize this impedance by controlling a capacitor through thyristors.

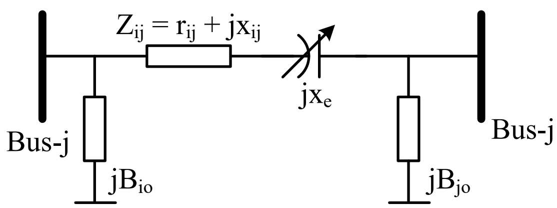


Fig. 1: A simple placement of TCSC in transmission bus.

Where $R_{ij}$ and $X_{ij}$ are represent resistance and reactance of the line. a half line charging susceptance are indicated by of $B_{io}$ and $B_{jo}$ respectively.

The susceptance difference of two lines before and after TCSC is given by

$$\Delta y_{ij} = y_{ij}^{'} - y_{ij} = (g_{ij}^{'} + jb_{ij}^{'}) - (g_{ij} + jb_{ij}) \qquad (1)$$

Where,

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

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

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

With adding TCSC, a new system with a set of admittance matrices can be described by the equation below.

$$Y'_{bus} = Y_{bus} + \begin{bmatrix} 0 & 0 & 0 & \ldots & 0 & 0 & 0 \\ 0 & \Delta y_{ij} & 0 & \ldots & 0 & -\Delta y_{ij} & 0 \\ 0 & 0 & 0 & \ldots & 0 & 0 & 0 \\ \ldots & \ldots & \ldots & \ldots & 0 & \ldots & 0 \\ 0 & 0 & 0 & \ldots & 0 & 0 & 0 \\ 0 & -\Delta y_{ij} & 0 & \ldots & 0 & \Delta y_{ij} & 0 \\ 0 & 0 & 0 & \ldots & 0 & 0 & 0 \end{bmatrix} \begin{matrix} \\ row-i \\ \\ \\ \\ row-j \\ \\ \end{matrix} \quad (2)$$

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

The above equations (1) and (2) can help to model TCSC in MATLAB with mathematical expressions. From eq. (2), it is clearly shown that the significance of TCSC.

## 3. Formation of Problem Statement

Optimization of the system performance required an optimal power system operation on an objective function.
The objective function needs to be set under different constrains. The formation of optimal power flow problem can be expressed by below fundamental equations.

Minimize $J(x,u)$ (3)

Subject to

$$g(x,u) = 0$$
$$h(x,u) \le 0$$

$x$ : Vector of system state variables.
$u$ : Problem vector of control variable.
$J(x,u)$ : Objective function to be minimized.
$g(x,u)$ : Equality Constraints.
$h(x,u)$ : Inequality Constraints..

Generator voltages $V_G$.

$P_G$ Represents generated real power.

Power at slack bus is $P_{G_1}$.

Settings for the transformer tap and shunt VAR compensation.
Therefore, the function ($u$) can be expressed as:

$$u^T = [V_{G1}..V_{GNG}, P_{G2}..P_{GNG}, T_1..T_{NT}, Q_{C1}..Q_{CNC}] \quad (4)$$

Here, the term 'J'is represents the objective function. Therefore, the J function should be minimizing.

The cost of fuel used in power system needs to be minimizing to achieve a cost effective operation. The mathematical expression for this cost function is given below:

$$J = \sum_{i=1}^{NG} f_i (\$/hr) \quad (5)$$

Where the cost curve of $i^{th}$ generator is represented by *fi.* This function can be further expressed by:

$$f_i = a_i P_{G_i}^2 (\$/hr) + b_i P_{G_i} + c_i \quad (6)$$

Here, constant represented by $a_i$, $b_i$, and $c_i$.

To transmit the most power from the sending end to the receiving end, the active power losses must also be kept to a minimum. The power created by this could likewise be saved. Also, this can help to maximise the use of electricity generated. Here is an expression of the power loss goal function that needs to be minimised*:*

$$J = f_c(x,y) = \sum_{i=1}^{nline} Loss_i \quad (7)$$

The following restrictions must be followed in order to solve the aforementioned functions. Real and reactive power limitations on equality are expressed by:

$$P_{G_i} - P_{D_i} - P_i(V,\delta) = 0 \quad (8)$$

$$Q_{G_i} - Q_{D_i} - Q_i(V,\delta) = 0 \quad (9)$$

Here, $P_i = \sum V_i V_j (G_{ij} \cos\delta_{ij} + B_{ij} \sin\delta_{ij})$, and $Q_i = \sum V_i V_j (B_{ij} \cos\delta_{ij} - G_{ij} \sin\delta_{ij})$

In the similar manner, The inequality constraints are also expressed by:

$$P_{gi}^{\min} \le P_{gi} \le P_{gi}^{\max} \qquad i \in N_g$$

$$Q_{gi}^{\min} \le Q_{gi} \le Q_{gi}^{\max} \qquad i \in N_g$$

$$|S_k| \le S_k^{\max} \qquad k \in N_E$$

$$V_i^{\min} \le V_i \le V_i^{\max} \qquad i \in N_B$$

# 4. Solution of Problem Statement with GA

In this section the GA is implemented to find the solution for optimal power flow problem by considering power, voltage, transformers, and other devices involved in power system IEEE bus system. To enhance best performance, each control objective is encoded under different size by keeping a small size of the GA chromosome size small. A model layout of the system with GA is presented in Fig. 2.

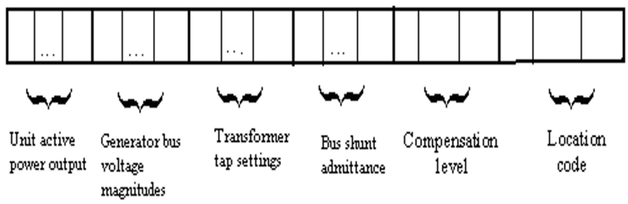


Fig. 2: Structure of.GA chromosome architecture.

The generation, evaluation, and genetic operations make up the GA that was used in this work. The number of chromosomes is used as a proxy for population size in the generation process. The population size has been predetermined. The size of the population affects how effective GA is. Its size, however, needed longer computing times. If it is too tiny, a local optimal solution results. Therefore, to achieve the best accuracy in minimum time under best resolution, a best suitable population size needs to be initiated for further process. A set of solutions for optimization is initiated in the evaluation process. A *"fitness function"* will be defined in this process to get a best solution. The fitness of each chromosome is evaluated in this process. The fitness function is chosen in a way that the best solution is the one that is closest to the overall ideal point. The GA's adaptability is one of its strengths. The procedure begins the genetic operation after determining the fitness function in one iteration or mutation. In genetic operation, the new population is created by generating new chromosomes. More population can be created by best fitness function which is near to the solution. This process involves *reproduction, crossover, and mutation.* A survival concept is also included to generate the new chromosomes by using best fitness values. The old chromosomes participated in mating process to reproduce new population based on their fitness value. High fitness values can produce high number of new chromosomes to increase the population of next generation. The crossover process takes place with two parents which are selected based on fitness value to produce two children. Newborns are anticipated to be healthier than parents and to share some of the parents' valuable traits. To sustain the potential diversity, mutations can produce a large number of new populations. In each string contains its random value may be zero or 1. The limitation value of mutation is further compared with this random value. Mutation will be preferred if it is less.

# 5. Results and Discussions

In a MATLAB script, the suggested GA-based optimal power flow with TCSC is created. On the standard 30 and 75 IEEE bus, the developed code has been tested. The tables below show the cost coefficients for the IEEE 30 bus system and 75 bus system. It is observed that the power losses are increasing while optimizing fuel cost. In other hand, optimizing the fuel cost cause the increasing in power loss cost. However, our objective is to identify the best combination of these two cost functions using GA. Hence both cost functions are now considered as multi objective functions.
Case-A: for a bus system that adheres to IEEE 30.

GA parameters are.
The population is 40.
Probability of elitism is 0.15
100 generations maximum.
Probability of crossing over is 0.95.
Probability of mutation = 0.001.

Table 1 OPF results for the IEEE 30 bus system with the goals of minimising active power loss and fuel costs.

| Generator busno | Active power outputs(without TCSC) | Active power outputs(with TCSC) | Fuel cost(without TCSC) | Fuel cost with(TCSC) |
|---|---|---|---|---|
| 1 | 108.62 | 92.23 | 261.480 | 216.350 |
| 2 | 48.260 | 46.940 | 125.210 | 120.70 |
| 5 | 34.910 | 34.840 | 111.07 | 110.70 |
| 8 | 29.370 | 27.460 | 97.24 | 90.80 |
| 11 | 15.360 | 16.510 | 52.44 | 56.340 |
| 13 | 52.450 | 50.180 | 226.12 | 213.490 |

From above table, both power loss and fuel cost and are considered in objective function. Total fuel cost decreased from 872.6670$/hr to829.400$/hr, and active power losses from 5.72550MW to 5.4220MW.

**$P_{gmax}$ and $P_{gmin}$ for generators**

| **Generator bus no** | $P_{gmin}$ | $P_{gmax}$ |
|---|---|---|
| 1 | 0.50 | 2.00 |
| 2 | 0.20 | 0.80 |
| 5 | 0.15 | 0.50 |
| 8 | 0.10 | 0.35 |
| 11 | 0.10 | 0.30 |
| 13 | 0.20 | 0.80 |

**a, b, c constants for generators**

| **Generator No** | **c** | **b** | **a** |
|---|---|---|---|
| 1 | 0 | 2.0 | 0.00375 |
| 2 | 0 | 1.75 | 0.0175 |

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| | | | |
|---|---|---|---|
| 3 | 0 | 1.0 | 0.0625 |
| 4 | 0 | 3.25 | 0.002075 |
| 5 | 0 | 3.0 | 0.025 |
| 6 | 0 | 3.0 | 0.024 |

**Case-B:-75 bus Indian practical system.**
Population size for the GA is 40.
100 is the maximum number of generations.
Probability of elitism is 0.15.
Probability of crossing over is 0.94.
Probability of mutation is 0.0015..

A standard Indian 75 IEEE bus system is depicted in Fig3.

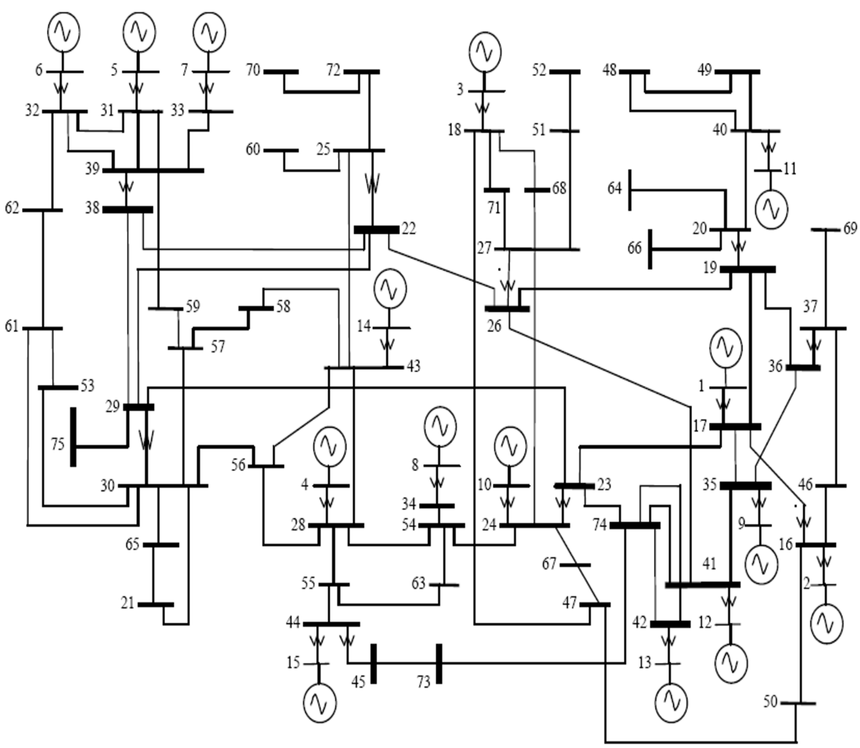


Fig. 3: A standard 75 IEEE bus system.

**Parameters of a, b, c with proposed method**

| Generator No. | a(INR/MW$^2$-h) | b(INR/MW-h) | C(INR/h) |
|---|---|---|---|
| 1 | 0.1258 | 1419 | 3855 |
| 2 | 0.0629 | 1480 | 1928 |
| 3 | 0.1132 | 1435 | 3470 |
| 4 | 0.0671 | 1484 | 1395 |
| 5 | 0 | 0 | 709.1 |
| 6 | 0 | 0 | 2306 |
| 7 | 0 | 0 | 384.3 |

| | | | |
|---|---|---|---|
| 8 | 0.0252 | 1497 | 771 |
| 9 | 0.2202 | 1253 | 6746 |
| 10 | 0.0220 | 1498 | 674.6 |
| 11 | 0.0409 | 1491 | 1253 |
| 12 | 0.2831 | 1092 | 8674 |
| 13 | 0.1415 | 1398 | 4337 |
| 14 | 0.2400 | 1742 | 1926 |
| 15 | 0.1049 | 951.3 | 2174 |

**Comparison between with and without TSCS**

| Generator busno | outputs of active power (without TCSC) | outputs of active power (with TCSC) |
|---|---|---|
| 2 | 1.9030 | 0.8050 |
| 3 | 1.6330 | 1.4600 |
| 4 | 0.8380 | 1.9830 |
| 5 | 0.8720 | 0.9870 |
| 6 | 0.9410 | 0.7100 |
| 7 | 0.8870 | 0.9820 |
| 8 | 5.1480 | 5.4430 |
| 9 | 2.3060 | 1.7740 |
| 10 | 1.9240 | 1.0250 |
| 11 | 2.1520 | 1.9370 |
| 12 | 8.5200 | 8.7510 |
| 13 | 1.3860 | 1.0900 |
| 14 | 3.2870 | 3.4720 |
| 15 | 7.8410 | 7.9380 |

From above table, observed that fuel consumption cost reduced to7896.70$/hr from 8044.8$/hr and similarly, loss of active power decreased to 155.970MW from 176.070MW by using TCSC.

## 6. Conclusion

In order to reduce both fuel costs and power losses, an optimal power flow with TCSC employing GA is proposed in this work. The suggested solution results in an efficient AC transmission system at the lowest possible system cost. In 30 IEEE standard bus system, it was noted that using TCSC caused the fuel cost to drop from 849.410 to 828.3320 dollars per hour during single objectives. Power losses decreased at the same period from 4.32850MW to 3.49250MW. Fuel cost decreased from 872.6670$/hr to 829.400$/hr dollars per hour during both objective functions, while active power losses decreased from 5.72550 to 5.4220 megawatts. Fuel and power losses for the 75 IEEE standard bys system are decreased to 7947.70$/hr and 141.160MW, respectively, in single objective functions. It was possible to cut fuel costs from $8044.00 per hour to $7896.70 per hour and power losses from 176.070 MW to 155.970 MW by taking both into account while calculating the target function. By taking into account how TCSC operates, this is achievable.

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