Enhancement of Transmission Power Capability in A Power System using Optimization Technique

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Abstract - The Thyristor Controlled Series Capacitor (TCSC) is one of the most effective Flexible AC Transmission System (FACTS) devices. It offers smooth and flexible control of the line impedance with much faster response compared to the traditional control devices. While numerous studies concerning the utilization of these devices, have been carried out so far, most of the research has focused on issues such as transient stability improvement, transmission line loss reduction, damping of power swings, voltage collapse, etc. In this paper, the modeling of TCSC for power flow studies has been discussed and presented in detail. The Newton-Raphson ac power flow method was used to perform the above studies. The performance of the proposed algorithm has been tested for IEEE-30 bus systems. It has also been observed that the proposed algorithm can be applied to larger systems and do not suffer with computational difficulties. This project investigates the use of TCSC to maximize total transfer capability generally defined as the maximum power transfer transaction between a specific power-seller and a power-buyer in a network. For this purpose, propose one of the Evolutionary Optimization Techniques, namely Differential Evolution (DE) to select the optimal location and the optimal parameter setting of TCSC which minimize the active power loss in the power network, and compare it’s performances with Genetic Algorithm (GA). To show the validity of the proposed techniques simulations will be carried out on an IEEE-30 bus power system.

Keywords - Thyristor Controlled Series Capacitor (TCSC), Differential Evolution (DE), Genetic Algorithm (GA), Power flow, optimal location, IEEE-30 Bus power system.

I. INTRODUCTION

The increasing Industrialization, urbanization of life style has lead to increasing Dependency on the electrical energy. This has resulted into rapid growth of power systems. This rapid growth has resulted into few uncertainties. Power disruptions and individual power outages are one of the major problems and affect the economy of any country. In contrast to the rapid changes in technologies and the power required by these technologies, transmission systems are being pushed to operate closer to their stability limits and at the same time reaching their thermal limits due to the fact that the delivery of power have been increasing. With the rapid development of power electronics, Flexible AC Transmission Systems (FACTS) devices have been proposed and implemented in power systems. The application of FACTS in electric power system is intended for the control of power flow, improvement of stability, voltage profile management, power factor correction, and loss minimization [1]. Among the FACTS devices, Thyristor Controlled Series Capacitor (TCSC) is a variable impedance type series compensator and is connected in series with the transmission line to increase the power transfer capability, improve transient stability, reduce transmission losses and dampen power system oscillations. Electric power flow problem is the most studied and documented problem in power engineering. In essence, this problem is the calculation of line loading given the generation and demand levels. Load flow calculation provide power flows and voltages for a specified power system subject to the regulating capability of generators, condensers, and tap changing under load transformers as well as specified net interchange between individual operating systems. This information is essential for the continuous evaluation of the current performance of a power system and for analyzing the effectiveness of alternative plans for system expansion to meet increased load demand. These analyses require the calculation of numerous load flows for both normal and emergency operating conditions

New algorithm for the optimal power flows incorporating with TCSC device have been developed as well as for the optimal placement of TCSC in the last two decades. A Newton- Raphson load flow algorithm to solve power flow problems in power system with
thyristor controlled series capacitor (TCSC) was proposed in [1], [2], [3], [4]. Reference [5] suggested a loss of sensitivity index to obtain the optimal placement of TCSC. Genetic Algorithm was proposed for solving the optimal location of FACTS in [2]. Differential Evolution Optimization technique for optimal location of FACTS devices was also proposed in [1]. In this project, one of the newest Evolutionary Algorithms (EAs) techniques, namely DE, is applied to find out the optimal location and parameter setting of the TCSC with the consideration of active power loss reduction in the power system. The performance of DE technique is also compared with that of Genetic Algorithm (GA).

1. About TCSC

Below figure (1) represents the modelling of TCSC

Fig. 1 : Modelling of TCSC

TCSC is series connected type FACTS device. The TCSC consist of a capacitor bank and a thyristor controlled inductive branch connected in parallel and connected in series to the transmission line. Its aims to directly control the overall series line impedance of the transmission line to improves power transfer capacity of the line. The operating range of TCSC is given by -0.7Xl to 0.2Xl.

II. PROBLEM FORMULATION

Main objective of this work is to find out the optimal location and optimal parameter setting of the TCSC in the power network to minimize the loss of the power system. The presence of TCSC into a power system brings many benefits, they are enhances the power transfer capability, transient stability and reduce transmission losses and dampen power system oscillations of a transmission line. For the placement of TCSC following loss of sensitivity index is selected.

The TCSC should be placed on a line (m) having most positive loss sensitivity index [3]. In this paper work includes a case namely reduction of active and reactive power loss. In this case TCSC device is included in the problem formulation. The results are obtained by considering practical IEEE 30-bus system. OPF solution is obtained on this system to determine the optimum generation schedule that satisfied the objective of minimizing the losses from the desire transactions and controlling of voltage magnitude.

IV. METHODOLOGIES FOR OPTIMAL LOCATION OF TCSC

A. Overview of Differential Evolution (DE)

Storn and Price first proposed the DE algorithm in 1995 [6]. DE is a novel parallel direct search method which utilized NP parameter vectors as a population for
each generation \( G \). DE is a typical Evolutionary Algorithm (EA), it generates a randomly distributed initial population \( g P \) with D dimensional variable vectors \( x_{i,g} \) \[8\]. Basically, DE generates new vectors of parameters by adding the weighted difference between two population vectors to a third one. If the resulting individual provides a smaller objective function value than a predetermined population individual, in the next generation the new individual replaces the one with which it is compared; otherwise, the old individual is retained. There are several variants of DE, \[10\]. The general notation of DE variants can be expressed as follows:

\[
\text{DE} / x / y / z
\]

Where \( x \) denotes the mutated vector, \( y \) is the number of difference vectors, and \( z \) is the crossover scheme. The advantage of DE \[11\] can be summarized as follows: DE is an effective, fast, simple, robust, inherently Parallel, and has few control parameters need little tuning. It can be used to minimize non-continuous, non-linear, non-differentiable space functions, also it can work with noisy, flat, multi-dimensional, and time dependent objective functions and constraint optimization in conjunction with penalty functions. 1) DE-based optimal location and parameter setting of TCSC:

The step by step implementation of DE algorithm can be described as follows:

**Step I.** Initialize the data for power flow and DE related parameters such as the size of population (NP), the maximum number of iteration or generation (Gmax), the number of variables to be optimized (D), CR, and F.

**Step II.** The population is a fixed size floating-point array. Since there is no a priori knowledge available about the global optimum, DE uses a nature way to generate the initial population \( p_0 \) by:

\[
p_0 = x_{i,j=0} = \text{rand} \times [0, 1], (x_j^u - x_j^l) + x_j^l
\]

\( i=1,2, \ldots, \ldots, \text{NP}, \quad j=1,2, \ldots, \ldots, \text{D} \)

The initial population is a set of values that are randomly chosen considering the variables that should be optimized (i.e., the location and the parameter setting of TCSC). These parameters are randomly initialized within feasible ranges. Therefore, all the solutions are feasible solutions and the goal is to find the optimal one. For example, the location of TCSC can be any line in the network except where the transformers are installed.

**Step III.** Evaluate the fitness for each individual in the population according to the objective function in (1).

**Step IV.** Create a new population by:

1. **Mutation:** One popular version of DE generates the new vectors according to the following equation:

\[
V = x_{r1,g} + F \cdot (x_{r2,g} - x_{r3,g})
\]

With random vectors \( r1, r2, r3 \in \{1, 2, \ldots, \text{NP}\} \).

Crossover: Crossover is the complementary process to increase the diversity of the parameter vectors by choosing a subgroup of parameters for mutation in DE. Mathematically, it can be illustrated as:

\[
u_{i,j} = \begin{cases} v_{i,j} & \text{for } j = (n)_{D}, (n + 1)_{D}, \ldots, (n + l)_{D} \\
(x_{i,g})_j & \text{for all other } j \in \{0, D-1\}
\end{cases}
\]

(5)

Selection: Selection specifies under what conditions the new vectors can enter into the population. The selection criterion of DE can be expressed as follows:

\[
x_{i,g+1} = \begin{cases} u_{i,g+1} & \text{if } f(u_{i,g+1}) < f(x_{i,g}) \\
x_{i,g} & \text{otherwise}
\end{cases}
\]

(6)

The parent vector \( x_{i,g} \) will be replaced by the child vector \( u_{i,g+1} \) only if it improves the objective \( f(x) \).

**Step V:** stop the process and print the best individual (optimal location and optimal parameter setting of TCSC) if the stopping criterion is satisfied, else go back to step IV.

**B. Overview of Genetic Algorithm**

The genetic algorithm (GA) used in the proposed algorithm is a simple version where three operators were used: reproduction, crossover and mutation. The reproduction consists of the selection and the process of copying the genetic information of the individuals to create a new population. The crossover is the genetic information exchange of two strings that are selected from the population at random with a crossover probability fixed at 0.7. Mutation is the process of random alteration of the value of the string position with a mutation probability fixed at 0.001. The goal of the genetic algorithm is to find the best locations of a given number of FACTS devices in accordance with a defined criterion. A configuration of \( NF \) FACTS devices is defined with two parameters: the location of the devices...
and heir parameters. An individual string used in genetic algorithm is represented with two substrings. The length of the first substring is \( nl \) where as the second substring is \( Na \) (gene length) [6]. The first substring corresponds to the optimal location of the FACTS devices. It contains 1’s and 0’s of length \( nl \), no. of lines in the system. 1 represents that FACTS device is present and 0 represents that FACTS device is not present. The bit number from the left gives the line in which FACTS device is located or not. Hence the length of first substring is kept equal to number of lines in the system. The second substring of the individual represents the parameter values of the TCSC device (\( \alpha \)), in the proposed model the substring represent as many values of \( \alpha \) equal to the number of devices available in the first string. The length of this substring is taken as \( Na*NF \). Where, \( Na \) is the gene length for encoding the value of \( \alpha \) in binary form and \( NF \) is the number of FACTS devices to be located in the system. Then evaluate the objective function(as per the equation 3.1) for each individual strings generated. The population size is the number of individual strings generated and it is taken as 200 in this work. Stopping criteria is set by maximum number of generations had been attained or not. If so, stop the program and take the best individual and its fitness function [6].

1) Flow chart for GA

![Flow chart for GA](image)

2) An Advanced Computational Refinement of GA

The crossover previously mentioned is the kernel of genetic operations. It promotes the exploration of new regions in the search space using randomized mechanism of exchanging information between strings. Two individuals previously placed in the mating pool during reproduction are randomly selected. A crossover point is then randomly selected and information from one parent up to the crossover point is exchanged with the other parent. This is specifically illustrated below for the used simple crossover technique, which was adopted in this work.

Parent 1: 1011:: 1110 offspring 1: 10111011
Parent 2: 1010 ::1011 offspring 2: 1010 1110

Another process also considered in this work is the mutation process of randomly changing encoded bit information for a newly created population individual. Mutation is generally considered as a secondary operator to extend the search space and cause escape from a local optimum when used prudently with the selection and crossover schemes.

V. SIMULATION RESULTS

A MATLAB codes for Differential Evolution, Genetic Algorithm and modified power flow algorithm to include TCSC were developed and incorporated together for the simulation purpose. To investigate the validation of the proposed techniques, both of Differential Evolution and Genetic Algorithms have been tested on the following two test system an IEEE-30 bus system shown in below fig3. The data for above mentioned system is taken from[14],[15],[16], respectively.

![Fig. 3. The IEEE-30 bus system.](image)
the TCSC. The parameters utilized in this simulation are shown in Table 1.

Table 1. Parameter Values for DE Parameter of DE

<table>
<thead>
<tr>
<th>Parameter of DE</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population size NP</td>
<td>20</td>
</tr>
<tr>
<td>Maximum number of generation ( G_{\text{max}} )</td>
<td>100</td>
</tr>
<tr>
<td>Number of variables (NV)</td>
<td>1</td>
</tr>
<tr>
<td>DE-step size, ( F )</td>
<td>0.5</td>
</tr>
<tr>
<td>Crossover probability constant CR</td>
<td>Between 0 and 1</td>
</tr>
<tr>
<td>DE strategy</td>
<td>DE/rand/1/bin</td>
</tr>
<tr>
<td>Termination criteria</td>
<td>( 1*\text{e}^{-6} ) or ( G_{\text{max}} )</td>
</tr>
</tbody>
</table>

1. IEEE-30 Bus Test System

The optimal placement of TCSC for this system is in line number 26 was found using loss of sensitivity index and the TCSC reactance \( x_{\text{TCSC}} = -49.1496 \). Power loss minimization is shown in Table 2.

Table 2. Active and reactive power losses with and without TCSC

<table>
<thead>
<tr>
<th>30-bus system</th>
<th>( P_{\text{loss}} )</th>
<th>( Q_{\text{loss}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before placing TCSC</td>
<td>17.528</td>
<td>34.553</td>
</tr>
<tr>
<td>After placing TCSC</td>
<td>17.4037</td>
<td>32.333</td>
</tr>
</tbody>
</table>

![Fig4. Power losses-100 generations](image)

Fig 4 sows the variation of power losses with no of iterations in DE.

B. Implementation of Genetic Algorithm

The proposed Algorithm was implemented to find the optimal location and proper setting of TCSC. Simple crossover, deterministic sampling selection, and non-uniform mutation have been adopted for the used GA. The other GA parameters are tabulated below in Table 3.

In this study, the location and the reactance of the TCSC were considered as variables optimized to reduce the system losses. Therefore, the TCSC is modeled for the load flow computation like a controllable reactance inserted in the system branch, which can increase or decrease the line reactance. The working reactance range of the TCSC was considered to be \([-0.05, 0.05]\].

Table 3. Parameter Values for GA

<table>
<thead>
<tr>
<th>Parameter of GA</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of variables</td>
<td>1</td>
</tr>
<tr>
<td>Number of chromosomes</td>
<td>20</td>
</tr>
<tr>
<td>Maximum number of generations</td>
<td>100</td>
</tr>
<tr>
<td>Number of off spring per pair of parents</td>
<td>1</td>
</tr>
</tbody>
</table>

For IEEE-30 bus systems, the GA was applied in simulation case. The simulation was done with an initial population having 20 individuals with a maximum generation number equal to 20 respectively, the results are shown as follows:

2. IEEE-30 Bus System

Simulation results shown that the optimal location of TCSC in this system is in line number 26 and the TCSC reactance \( x_{\text{TCSC}} = -50.1087 \). The simulation results for active and reactive power loss with and without TCSC for this system are tabulated in below table 4.

Table 4. Active and reactive power losses with and without TCSC

<table>
<thead>
<tr>
<th>30-bus system</th>
<th>( P_{\text{loss}} )</th>
<th>( Q_{\text{loss}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before placing TCSC</td>
<td>17.528</td>
<td>34.553</td>
</tr>
<tr>
<td>After placing TCSC</td>
<td>17.4057</td>
<td>32.443</td>
</tr>
</tbody>
</table>

![Fig5. Power loss-100 generations](image)

Fig. 5.: Power loss-100 generations
Fig 5 shows the variation of power losses with no of iterations in GA.

Table 5 shows the comparison of Differential Evolution and Genetic Algorithms shown in below table.

Table 5. Active and reactive power losses for DE and GA

<table>
<thead>
<tr>
<th></th>
<th>DE</th>
<th>GA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ptlloss</td>
<td>17.4037</td>
<td>17.4057</td>
</tr>
<tr>
<td>Qtlloss</td>
<td>32.333</td>
<td>32.443</td>
</tr>
</tbody>
</table>

From Table 5, it was observed that the proposed technique namely, Differential Evolution Algorithm is more better compared with the Genetic Algorithm.

VI. COMPARISON BETWEEN THE PERFORMANCE OF GA AND DE

In the following, we summarize the main observations that we have noticed from the implementation results:

Both DE and GA are sensitive to the control parameters

(a) In general; DE is simple, accurate, and robust. It convergence fast and finds the global optimum almost in every run. In addition, it has few parameters to tune, and the same settings can be used for many different problems.

(b) From the convergence perspective, it is observed that DE outperforms GA. DE is able to achieve good results consistently with fast performance. It finds the smallest value of the objective function in all studied cases. If the computational time is not important, GA always achieves good solutions. When the computational time is considered as the priority, DE is the good choice.

(c) From the perspective of convergence speed, it is observed that DE is always faster than GA.

(d) DE and GA are robust techniques: the performed 100 trials show that DE and GA can achieve the same results consistently over many trials.

(e) DE uses real number representation while the conventional GA uses binary, although it sometimes uses integer or real number representation as well.

(f) In GA, two parents are selected for crossover and the child’s recombination of the parents. In DE, three parents are selected for crossover and the child is a perturbation of one of them.

(g) The new child in DE replaces a randomly selected vector from the population only if it is better than it.

In conventional GA, children replace the parents with some probability regardless of their fitness.

(i) A random choice of the vector of differentiation produces many useless steps in the global neighbourhood, and a local search is needed at the end of optimization.

(j) Both DE and GA are sensitive to the control parameters.

VII. CONCLUSION

In this paper, to select the optimal rating of TCSC one of the computational intelligence technique used namely: Differential evolution technique. The performance of the DE is compared with that of GA(Genetic Algorithm). By considering these two techniques for electrical power systems it is beneficial to electrical utility to transfer the power with minimum losses. By observing the results of proposed two techniques, Differential Evolution algorithm was best technique to minimizing the losses compared with the Genetic Algorithm.

VIII. REFERENCES


