Optimal Placement Of Thyristor Controlled Series Capacitor For Loss Minimization In A Power System

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Abstract

Flexible Alternating Current Transmission Systems(FACTS) devices represents a recent technological development in electrical power systems, which makes utilities able to control power flow, increase transmission line stability limits, and improve security of transmission system . In a multi machine network, the influence of TCSCs on the network flows is complex since the control of any one device influences all others. In a competitive (deregulated) power market, the location of these devices and their control can significantly affect the operation of the system. 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 and for comparison purposes, simulations will be carried out on an IEEE-14 bus power system. The results will expect that DE is quantitatively an easy to use, fast, robust and powerful optimization technique compared with genetic algorithm (GA).

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

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. 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.

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

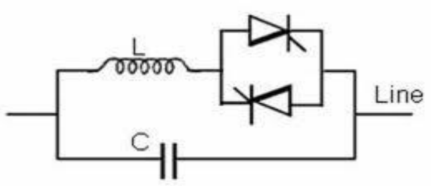

Fig 1.Modelling of TCSC

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. Considering the control parameters line reactance (X_{ij})for TCSC placed between bus i and j and reactive power (Q_{ij}), the power loss sensitivity index with respect to this control variable can be formulated in[3] as

$a_{ij}=\frac{\partial Q_L}{\partial X_{ij}}$Loss sensitivity with respect to TCSC

This factor can be computed at a base load flow solution as given bellow. Consider a line connected between bus I and j and having a net series impedance of X_{ij} and Q_i is the net reactive power injected in the bus i. The bus sensitivity index with respect to X_{ij} is computed in [3] as

$$\frac{\partial Q_L}{\partial X_{ij}} = [{V_i}^2+{V_j}^2 - 2V_iV_j\cos(\delta_i - \delta_j)]\frac{{R_{ij}}^2-{X_{ij}}^2}{({X_{ij}}^2+{R_{ij}}^2)^2}$$
(1)

Where

$$Q_L=\Sigma^n \sum_{i=1 j=1}^{n} \gamma_{ij}\left(P_iP_j + Q_iQ_j\right) + £(Q_jP_i - P_jQ_i)$$
(2)

Where

Q_L Is the Reactive power loss.
X_{ij} Is the series impedance between bus i and j.
V_i,V_J are the voltage magnitude at the bus i and j.
R_{ij} Is the resistance between bus i and j.
δ_i,δ_j Are the power angle at bus i and bus j.
P_i,P_j Are the active powers at the bus i and bus j.
Q_i,Q_j Are the reactive powers at bus i and bus j.
$£,\gamma$ Are the loss coefficients.

III. CRITERIA FOR OPTIMAL PLACEMENT

The TCSC device should be placed on the most sensitivity bus or line. For the TCSC the location is the line most positive sensitivity index, with the loss sensitivity indices computed for the TCSC device, following criteria has been used for optimal placement.

The TCSC should be placed on a line (m) having most positive loss sensitivity index a_k[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 14-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 $X_{j,i,g}$ [5].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, [7]. The general notation of DE variants can be expressed as follows:

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 [8] 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 prior knowledge available about the global optimum, DE uses a nature way to generate the initial population $p_0$by:

$$p_0=X_{j,i,g=0} = rand_j\,[0,1].\left({x_j}^u - {x_j}^l\right) + {x_j}^l$$
(3)

i=1,2,……….,NP, j=1,2,……….,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:

$$V = x_{r1,g} + F.(x_{r2,g} - x_{r3,g}) \quad (4)$$

With random vectors of $r_1, r_2, r_3 \in \{1,2......NP\}$.

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:

$$U = (u_1, u_2 ......, u_D)^T$$

$$u_{i,j} = \begin{cases} v_{i,j} \text{ for } j = (n)_D, (n+1)_D, ..., (n+l1)_D \\ (x_{i,g})_i \text{ for all other } j \in [0, D-1] \end{cases} \quad (5)$$

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

$$x_{i,(g+1)} = \begin{cases} u_{i,(g+1)} \text{ if } f(u_{i,(g+1)}) < f(x_{i,g}) \quad (7) \\ x_{i,g} \text{ otherwise} \end{cases} \quad (6)$$

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

GA is an evolutionary computing method in the area of artificial intelligence. It was pioneered by Holland in the 60'sand 70's and his work is comprehensively presented in [9].It is a global search algorithm that is based on concepts from natural genetics and the Darwinian survival-of-the-fittest code. Meta-heuristic algorithm-based engineering optimization methods, including GA, have occasionally overcome several deficiencies of conventional numerical methods. Genetics is usually used to reach to a near global optimum solution. In each iteration of GA (referred as generation), a new set of string (i.e. chromosomes) with improved fitness is produced using genetic operator (i.e. selection, crossover and mutation) [10].

1) A Brief Outline of GA Computational Tasks

The GA control parameters, such as population size, crossover probability and mutation probability are selected ,and an initial population of floating strings of finite length is randomly generated. Each of these individuals, comprising a number of chromosomes, represents a feasible solution to the search problem. Basically, average minimum and maximum fitness of all individuals within a generation are computed. If a pre-defined convergence criterion is not satisfied, then the genetic operations comprising selection and reproduction, crossover and mutation are carried out. Fundamentally, the selection and the reproduction mechanism attempt to apply pressure upon the population in a manner similar to that of the natural selection found in biological systems. A new population is created with worse performing individuals eliminated whilst the most highly fit members in a population are selected to pass on information to the next generation. In this work, the selection function called deterministic sampling selection is adopted. The method ensures that the bigger fitness individuals are remaindered into the next generation. Conceptually, pairs of individual's are chosen at random from the population and the fit of each pairs allowed to mate. Each pair of mates creates a child having some mix of the two parents.

2.Flow chart for GA

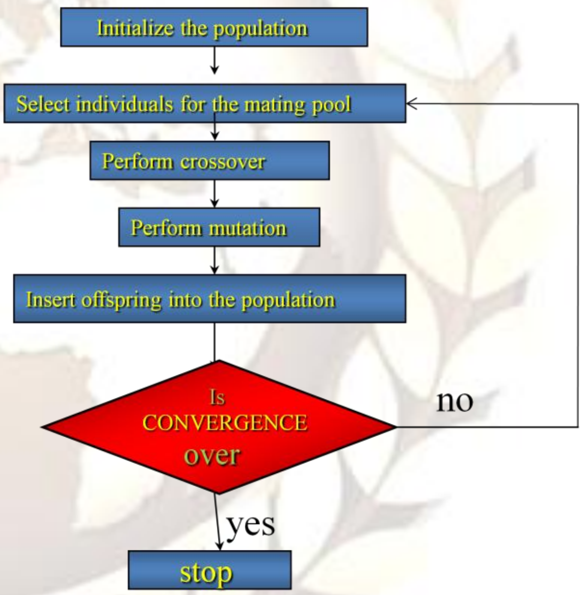

Fig 2.GA flow chart

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-14 bus system shown in below fig3.The data for above mentioned system is taken from[11],[12],[13], and [14] respectively.

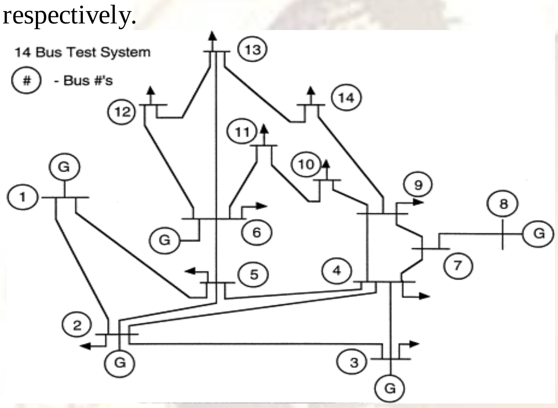

Fig3.The IEEE-14 bus system.

A. Implementation of Differential Evolution

Differential Evolution Optimization technique is also implemented in two numbers of generation100, to find out the optimal location and parameter setting of the TCSC. The parameters utilized in this simulation are shown in Table 1.

Table 1.Parameter Values For DE
Parameter of DE

Population size NP	20
Maximum number of generation G_{max}	100
Number of variables(NV)	2
Length of individual(LI)	2
DE-step size, F	0.5
Crossover probability constant CR	Between 0 and 1
DE strategy	DE/rand/1/bin
Termination criteria	$1{*}e^{-6}$ or G_{max}

1. IEEE-14 Bus Test system

The optimal placement of TCSC for this system is in line number 19 was found using loss of sensitivity index and the TCSC reactance x_{TCSC} =-48.1496.power loss minimization is shown in bellow Table 2.

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

	14-bus system	
	Ptl_{loss}	Qtl_{loss}
Before placing TCSC	13.5766	28.553
After placing TCSC	13.352	28.333

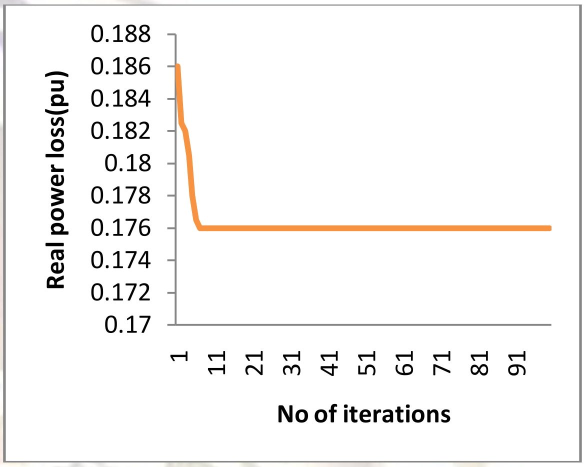

Fig4. Power losses-100 generations

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

Parameter of GA	
Number of variables	2
Length of variables	2
Number of chromosomes	20
Maximum number of generations	100
Number of off spring per pair of parents	1

For IEEE-14 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-14 Bus System

Simulation results shown that the optimal location of TCSC in this system is in line number 19 and the TCSC reactance x_{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

	14-bus system	
	Ptl_{loss}	Qtl_{loss}
Before placing TCSC	13.5766	28.553
After placing TCSC	13.372	28.443

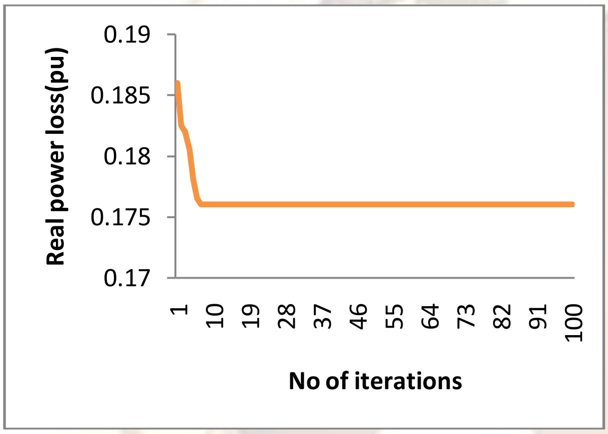

Fig5.Power loss-100 generations

Fig 5 sows 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

	DE		GA	
	Ptl_{loss}	Qtl_{loss}	Ptl_{loss}	Qtl_{loss}
14-bus system	13.352	28.333	13.372	28.443

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

VI. COMPARISSION 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 100trials 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 a 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 use one of the computational intelligence technique, 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.

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