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# Soft Computing Approach for Optimization of FACTS Devices to Control Transmission Power Losses

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*Abstract:* **Losses in power transmission are significant in absence of controlling devices. Considerable power consumption occurs due to heavy load on lines and production of power does not meet the requirement. Focus on reducing power wastage, control devices are employed with reactive impedances and thyristor switches to compensate inductive, resistive and capacitive losses in transmission. FACTS devices enhance power flow transfer capability and continuous control over voltage profile with improvement in system damping to minimize losses on a parallel note. In this research heuristic approach is tested to optimize FACTS devices that would further enhance the controlling action of device. TCSC is selected as control device and Genetic Algorithm, Particle Swarm Optimization and Differential Evolution are heuristic approach that would be tested. Results and simulations validate the superiority in performance of GA with TCSC over conventional TCSC.**

*Keywords:* **TCSC, Power Loss, Genetic Algorithm, Heuristic Approach**

## 1. INTRODUCTION

Transmission of power ranges from meters to kilometres. The long is the transmission line; higher would be the losses in transmission [3] [4] [6]. Researches demonstrate that 3 factors are major in domain of technical losses i.e. resistance, inductance and capacitance. The fixed losses are subjected to quality of material and environmental conditions, thus are out of scope of this paper.

The transmission line can be studied with the three constants: R (Resistance), L (Inductance) and C (Capacitance) [7]. These factors are distributed in a line uniformly across whole length. The inductance and the resistance are the two factors that form series impedance. The capacitance that exist between the conductors for a single phase line or from the conductor to neutral for the three phase line forms a shunt path across the length of the line [8]. Therefore the effects of capacitance introduce complications in the transmission line calculations. Overhead lines are classified on the basis of the presence of capacitance in a line.

Insufficient reactive power availability or non-optimized reactive power flow may lead a power system to insecure operation under heavily loaded conditions [1] [2]. By reallocating reactive power generations in the system by adjusting transformer taps, generator voltages and switchable VAR sources, the problem can be solved to a far extent. Power generated in power stations pass through large and complex networks like overhead lines, transformers, cables and other equipment and reaches at the end users. It is fact that the single unit of electric energy generated by Power Station does not match with the units distributed to the consumers. However, some percentage of the units is lost in the distribution network.

$$Transmission\ and\ Distribution\ Losses = \frac{(Energy\ Input\ to\ Feeder\ (Kwh) - Billed\ Energy\ to\ consumer\ (Kwh)}{Energy\ Input\ Kwh \times 100} \quad (1)$$

Some of the major transmission losses are mentioned here. [5] Describes the two types of technical losses i.e. permanent and Variable technical losses.

FACTS technologies offer competitive solutions to today's power systems in terms of increased power flow transfer capability, enhancing continuous control over the voltage profile, improving system damping, minimizing losses, etc. FACTS technology consists of high power electronics based equipment

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with its real-time operating control [9]. There are two groups of FACTS controllers based on different technical approaches, both resulting in controllers able to solve transmission problems.

Heuristic methods represent the wide range of computable global optimization techniques that employs novel approaches for intelligent search of optimal values. These have common characteristics of natural evolution, physical processes and stochastic events. Opposed to deterministic counterparts some of the noticeable features of these methods are they are completely problem independent, i.e. they neglect faithfulness to any mathematical requirements and have considerable simple and global implementable applications. Linearity, differentiability, convexity or Lipschitz continuity is irrelevant as the search is guided by different mechanisms. Even though these methods are unorthodox with minimal mathematical basis and convergence guarantee, they have proven their effectiveness and optimization strategies hence widening the area of implementation.

## 2. PROBLEM DEFINITION AND LITERATURE SURVEY

Naturally the power flow pattern can be influenced by changes of the impedances in the network. Similarly series compensation may be used as a means for adapting the load ability of certain critical lines that would risk to be operating with too large angle separation or amplitude deviations during contingencies. This in turn initiates lead-lag problem in controllers on which the researchers focused their work. Numerous algorithms tend to over-write the problem domain either by optimization or multi-objective formation.

Design of an optimal controller requires optimization performance measures that are often non-commensurable and competing with each other. Design of such a controller is indeed a particle swarm optimization (PSO) problem. The authors in this paper investigates the comparison of application of PSO based optimization technique and Differential Evolution (DE) for the design of a Thyristor Controlled Series Compensator (TCSC)-based supplementary damping controller [10].

Rajendra Prasad Narne [11] presents the modelling and simulation of a single machine infinite bus (SMIB) system with a power system stabilizer (PSS), and TCSC based controllers. Different controller structures namely Lead-Lag (LL) and a proportional-integral (PI) for TCSC Controller were proposed and comprehensive assessment effects of the tuned TCSC Controller on the test power system were carried out. Simulations were carried out in different loading conditions under a symmetrical three-phase short circuit fault occurs at generator terminals. Galam Ravi [12] in his work project investigated 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, they 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 its performances with Genetic Algorithm (GA).

A Genetic-based damping controller for a thyristor-Controlled Series Capacitor (GCSC) is presented in the paper oj M. A. Abido. The design problem of TCSC based stabilizer is formulated as an optimization problem where the genetic algorithm (GA) is applied to search for the optimal setting of the stabilizer parameter. Minimizing the real part of the system eigenvalue associated with low frequency oscillation mode was proposed as the objective function of the design problem. The proposed controller was examined on a weak connected power system with different disturbances and loading conditions. Eigenvalue analysis and nonlinear simulation results show the effectiveness of the proposed GCSC based stabilizer and its ability to provide efficient damping of low frequency oscillations [13].

Ali Yazdekhasti presents parameters setting by optimization algorithm of Particle Swarm Optimization (PSO) for modeling Thyristor Controlled Series Capacitor (TCSC) in power system. This is done by minimizing a time-domain based objective function of PSO. The results obtained from simulations in MATLAB/SIMULINK verified the effectiveness of proposed modeling and improving power system stability [14] [44].

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## 3. Thyristor Controlled Series Compensator

TCSC is provided with the capacitor bank, followed and shunted by a Thyristor Controlled Reactor (TCR) that provides a smooth variable series capacitive reactance. It is a single-port circuit coupled in series with the transmission line; it exercises natural commutation; with switching frequency is low; it also implements insignificant energy storage and do not have even a single DC-port. With the insertion of a capacitive reactance in series of line, inherent inductive reactance would lower the total effective impedance of the line and thus virtually decrements its length. As a result, both the voltage stability and angular stability gets improved. Moreover, in contrast to capacitors that are switched by circuit breakers, TCSC will be more efficient because of the thyristors that offers flexible adjustment, and more sophisticated control theories can be effortlessly applied.

Figure 1 shows the simple diagram of TCSC. This structure could be modeled as

$$X = X_0 + \Delta X \tag{2}$$

Where, $\Delta X = f(\Delta\omega g)$. $\Delta X$ is the capacitive reactance.

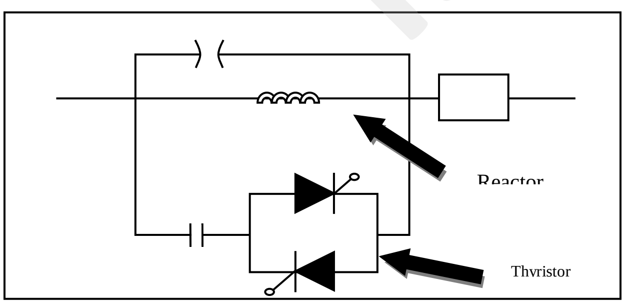


Figure 1: Simple Diagram of TCSC

The control offered by TCSC is an 'impedance' type control, i.e. the inserted voltage is proportional to line current. This type of control is generally best suited for the applications in power flow problems, where a well-defined phase angle difference exists between the ends of the transmission line to be compensated and controlled. The concept of controlled series compensation can be used for a wide range of objectives in the power system control technology. Naturally the power flow pattern can be influenced by changes of the impedances in the network. Similarly series compensation may be used as a means for adapting the load ability of certain critical lines that would risk to be operating with too large angle separation or amplitude deviations during contingencies.

Inserting a TCSC may alleviate such limitations thereby increasing the transfer capability of the transmission system. It is likely that installations of controllable series compensation will include both fixed and mechanically switched modules (MSSC) and thyristor controlled modules (TCSC) in a variety of combinations.

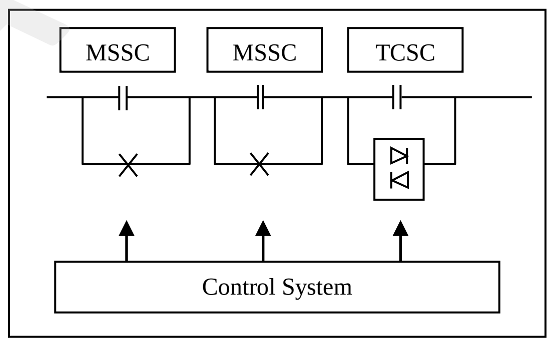


Figure 2: Outline of CSC with MSSC and TCSC

## 4. Heuristic Approaches For TCSC

### *Genetic Algorithm*

GA can be viewed as a general-purpose search method, an optimization method, or a learning mechanism, based freely on Darwinian principles of biological evolution, reproduction and "the survival of the fittest". GA keeps a track for the set of candidate solutions called population and repeatedly upgrades them. At every step, the GA selects individuals from the live population to be parents and uses them produce the children for the subsequent generation. Over successive chain of generations, the population evolves toward an optimal solution and

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remains in the genome composition of the population over traits with weaker undesirable characteristics. The GA is well suited to and has been extensively applied to solve complex design optimization problems because it can handle both discrete and continuous variables, nonlinear objectives and constrain functions without requiring gradient information [18].

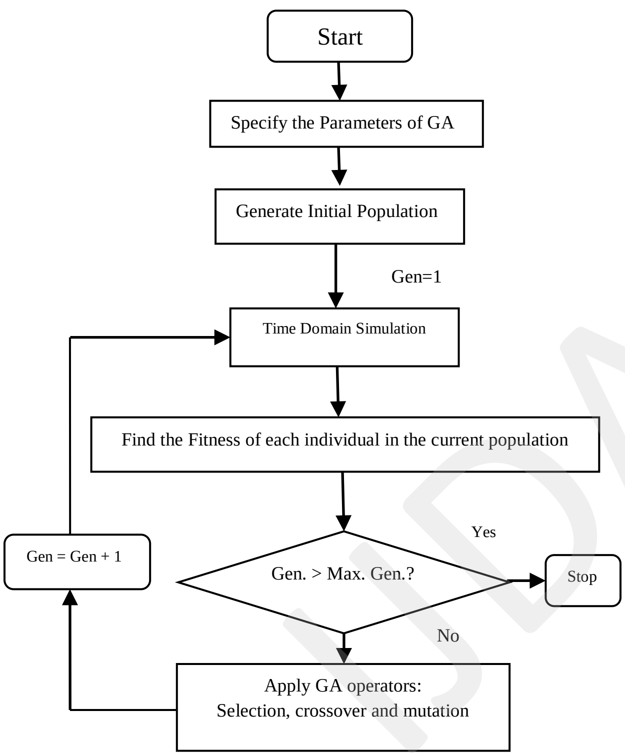


Figure 3: Genetic Algorithm Pseudo Code

A fitness or objective function is used to reflect the goodness of each member of the population. Given a random initial population, GA functions in definite pattern of cycles called as generations, as follows:

- Every member of the population is examined using a fitness function.
- The population undergoes reproduction in a number of iterations. One or more parent individuals are chosen stochastically, but strings that possess higher fitness values have higher probability of contributing an offspring.
- Genetic operators, for example mutation and crossover, are applied to parents to produce offspring.

The offspring individuals are then introduced into the population and the process is repeated.

***Particle Swarm Optimization***

Working Behavior of Particle Swarm Optimization:

Each particle tries to modify its position using the following information:

- The current positions,
- The current velocities,
- The distance between the current position and pbest,
- The distance between the current position and the gbest.

The adjustment of the particle's position can be mathematically modeled according the following equation:

$$V_i^{k+1} = wV_i^k + c_1\, rand_1(\ldots)\; x\; (pbest_{i-si}^k) + c_2\, rand_2(\ldots)\; x\; (gbest - s_i^k) \qquad (3)$$

Where,
$v_i^k$ : velocity of agent i at iteration k,
w: weighting function,
$c_j$ : weighting factor,
rand: uniformly distributed random number between 0 and 1,
$s_i^k$ : current position of agent i at iteration k,
$pbest_i$ : pbest of agent i,
gbest: gbest of the group.

The following weighting function is usually applied in above equation

$$w = w_{Max} - [(w_{Max} - w_{Min})\; x\; _{iter}]/maxIter \qquad (4)$$

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Where,
wMax= initial weight,
wMin = final weight,
maxIter = maximum iteration number,
iter = current iteration number.

$$s_i^{k+1} = s_i^k + V_i^{k+1} \tag{5}$$

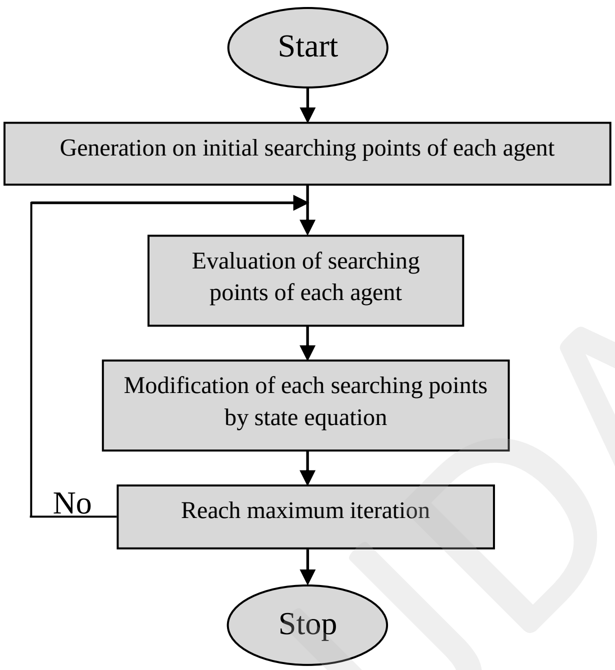


Figure 4: Flow Chart of PSO

***Differential Evolution***

Differential Evolution is the optimization technique dependent on the difference in pairs of object vectors sampled randomly to formulate mutation process. DE creates fresh individuals and select 3 individuals in random to optimize 1 individual. A new vector is created by adding a weighted (mutation factor) difference of two individual to the other. Crossover is not mandatory step of DE as compared to GA. The individuals are processed for evaluation of fitness for new individuals (better than old individuals). The process is executed till maximum generations or convergence is reached.

## 5. Results and Simulations

- With No Thyristor Controlled Series Compensator: POWER LOSS = 144.6958 MW
- With Thyristor Controlled Series Compensator positioned By GA @ BUSES 8, 13 & 21: POWER LOSS = 131.6284 MW
- With Thyristor Controlled Series Compensator positioned By PSO @ BUSES 13, 3 & 21: POWER LOSS = 129.4213 MW
- With Thyristor Controlled Series Compensator positioned By DE @ BUSES 13, 3 & 21: POWER LOSS = 129.4213 MW

## 6. Conclusion

In the context of our research for the minimization of Transmission Power Losses by the application of FACTS devices, a comparison is made in the three algorithms that were used to optimize with FACTS devices. The Differential Evolution, Particle Swarm Optimization and Genetic Algorithm were tested with the FACTS devices using the MATLAB model. The simulation results indicate the superior performance of FACTS with these three algorithms. A reduction in CPU time and Transmission Power Losses is reported when BSS method is employed along with Optimization Algorithm in comparison against the NR method. The tests were performed taking STATCOM as the FACTS device. The PSO and Differential Evolution algorithms have equal power losses that is slightly less than Genetic Algorithm and much better than the line without STATCOM device. Further the percentage reduction in CPU time using DE (BSS method) increases with the increase in size of power system.

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