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# Fuzzy based evolutionary algorithm for reactive power optimization with FACTS devices

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ABSTRACT

In this paper, optimization techniques such as Genetic Algorithm (GA) and Differential Evolution (DE) along with Fuzzy Logic (FL) is used for the optimal setting of power system variables, including Flexible AC Transmission Systems (FACTS) devices. Here, two types of FACTS devices, Thyristor Controlled Series Compensator (TCSC) and Static Var Compensator (SVC) are used for the optimal operation of the power system as well as in reducing congestion in transmission lines. Optimal placement of FACTS devices in the heavily loaded power system reduces transmission loss, controls reactive power flow, improves voltage profile of all nodes and also reduces operating cost. In this proposed approach fuzzy membership function is used for the selection of weak nodes in the power system for the placement of SVC's as one of the FACTS devices while the location of TCSC's are determined by the reactive power flow in lines. The proposed technique is compared with other optimization methods using different globally accepted evolutionary algorithms where the nodes are detected by eigen value analysis and the amount of FACTS devices are determined by evolutionary techniques like, Genetic Algorithm (GA), Differential Evolution (DE) and Particle Swarm Optimization (PSO). The superiority of the proposed fuzzy based optimization approach is established by the results and the comparative analysis with other methods.



## 1. Introduction

In the present day scenario, due to increase in power demand, restriction on the construction of new lines, environment, unscheduled power flow in lines creates congestion in the transmission network and increases transmission loss. Effective control of reactive compensation on weak nodes improves voltage profile, reduces power loss and improves both steady state and dynamic performance of the system. With the development of FACTS devices, it has now become an obvious choice to use them in today's power system to extract maximum advantage out of it. The concept of flexible AC transmission system (FACTS) was first introduced by Hingorani [1]. FACTS devices are solid-state converters having the capability of control of various electrical parameters in transmission circuits. Optimal location of FACTS devices for congestion management by controlling device parameters is discussed in [2]. The optimal location of Thyristor Controlled Series Compensator (TCSC) is presented in [3] for the reduction of transmission loss. Optimal reactive power dispatch along with the setting of switchable series and shunt FACTS devices is discussed in [4]. Optimal placement of Var sources by loss sensitivity based method is presented in [5]. In [6] authors have presented a new generalized current injection model for power transfer using TCSC, Unified Power Flow Controller (UPFC), Generalized Unified Power Flow Controller (GUPFC). Steady state optimization with series FACTS devices was the main objective of the work in [7]. Power flow model with multiple FACTS controller is presented in [8]. In [9] author has used TCSC for inductive as well as capacitive reactance compensation to increase the transmission line capacity. Kumar and Sekhar in [10] presented an approach using rescheduling of generators for congestion management with voltage stability constraint taken as loadability parameter into consideration along with the line security limits. A new technique as teaching learning based optimization (TLBO) and quasi-oppositional TLBO (QOTLBO) is presented in [11] for the solution of multi-objective optimal reactive power dispatch (ORPD) problems of power system by minimizing real power loss and voltage deviation. Optimal coordination of FACTS devices using evolutionary strategy is presented in [12]. Genetic Algorithm (GA) is used for the optimal setting of multi-type FACTS devices in [13]. The optimal locations and sizing parameters of multi-type FACTS devices using a graphical user interface (GUI) based on a Genetic Algorithm (GA) in large power systems is presented in [14]. A security constraint GA based approach in defining maximum loadability limit of a power system

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is presented in [15]. Particle Swarm Optimization (PSO) approach in handling FACTS devices in power system is presented in [16,17]. Various objectives of reactive power problem in interconnected power system and different solution techniques are addressed in [18]. Solution methodology and comparative analysis using DE and PSO algorithm with FACTS devices under different loading conditions is presented in [19]. Basu in [20] proposed Differential Evolution (DE) algorithm for the minimization of generator fuel cost using FACTS devices. Hybridization of DE and PSO (DEPSO) to determine the maximum loadability limit of power system is presented in [21]. Reactive power flow control using fuzzy-sets is discussed in [22]. In [23] the authors have introduced a technique for the use of fuzzy membership function in reactive power optimization. An optimal reactive power scheduling method to minimize active power loss and maximizes Voltage Stability Margin (VSM) using Fuzzy-LP method is dealt in [24]. A technique for placement and sizing of shunt FACTS controller with combined Fuzzy and GA approach for optimal reactive power reinforcement is discussed in [25]. Integration of Fuzzy Systems with Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) algorithm to solve the optimal power flow (OPF) problem for optimal setting of control variables is the theme of the paper [26]. In [27,28] authors main work is focused on fuzzy-based reactive power and voltage control to minimize real power loss.

In this paper two types of FACTS devices have been discussed namely TCSC (Thyristor Controlled Series Capacitor) and SVC (Static Var Compensator). The main objective of this paper is to find the optimal location of FACTS devices in the transmission network to minimize the transmission loss and also for the simultaneous increase of power transfer capacity of the transmission network that ultimately results minimum operating cost under different loading conditions. There are three main issues that are to be considered for the selection of FACTS devices, its types, its capacity and location where to be installed. Placement of FACTS devices is done on IEEE-30 bus test system in the present work. TCSC's are placed in lines where reactive power flows are very high, placement of SVC's is determined by the fuzzy membership of loss sensitivity in the weak nodes and the optimal parameter settings of these FACTS devices are governed by Genetic Algorithm and Differential Evolution. This combined Fuzzy-GA and Fuzzy-DE approach is compared with other simple evolutionary algorithmic approaches like Genetic Algorithm (GA), Differential Evolution (DE) and Particle Swarm Optimization (PSO), where detection of weak nodes is determined by eigen value analysis.

## 2. Modeling of FACTS devices

For an interconnected congested power network FACTS devices can be modeled as power injection model. The injection model describes the FACTS as a device that injects a certain amount of real and reactive power to a node. Both TCSC and SVC devices control the power flow and voltages by adjusting the reactance of the system.

### 2.1. Thyristor Controlled Series Compensator (TCSC)

Transmission line model with a TCSC connected between bus-$i$ and bus-$j$ is shown in Fig. 1. In steady state, the TCSC can be considered as an additional reactance $-jX_{TCSC}$. TCSC acts as either inductive or capacitive compensator by modifying transmission line reactance. By installing TCSC's in transmission line power capacity increases and also the voltage profile improves. The injection model of TCSC is shown in Fig. 2. Transmission line admittance with TCSC is represented by:

$$G_{TCSC} + jB_{TCSC} = \frac{1}{R_j(X_{Line} - X_{TCSC})} \quad (1)$$

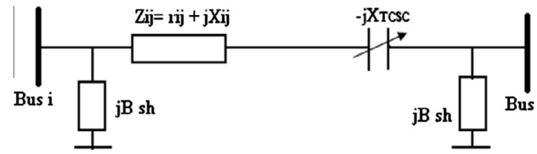


**Fig. 1.** TCSC model.

where $R$ and $X_{Line}$ are the resistance and reactance of the line without TCSC and $X_{TCSC}$ is the reactance with TCSC.

### 2.2. Static Var Compensator (SVC)

The SVC can operate either in capacitive mode or in inductive mode. The function of SVC is either to inject reactive power to the bus or to absorb reactive power from the bus where it is connected. It improves the voltage in static and dynamic conditions and reduces active power loss. The variable susceptance model of SVC is shown in Fig. 3.

The SVC's effective reactance is determined by the parallel combination of $X_C$ and $X_L$.

## 3. Cost function and problem formulation

According to [29], cost functions for TCSC's and SVC's are given below:

*TCSC:*

$$C_{TCSC} = 0.0015(TCSC_{value})^2 - 0.7130(TCSC_{value}) + 153.75(US/kVar) \quad (2)$$

*SVC:*

$$C_{SVC} = 0.0003(SVC_{value})^2 - 0.3051(SVC_{value}) + 127.38(US/kVar) \quad (3)$$

Here, $TCSC_{value}$ and $SVC_{value}$ is the operating values of the FACTS devices.

The main objective is to find the optimal location of FACTS devices along with network constraints so as to minimize the total operational cost and relieve transmission congestion at different loading conditions. Installation costs of various FACTS devices and the cost of system operation, namely, energy loss cost are combined to form the objective function to be minimized. Besides FACTS devices, transmission loss can be minimized by optimization of reactive power, which is possible by controlling reactive generations of the generator's, controlling transformer tap settings, and by the addition of shunt capacitors at weak buses.

The optimal allocation problem of FACTS devices can be formulated as:

$$C(T) = C_1(E) + C_2(F) \quad (4)$$

where $C_1(E)$ is the cost due to energy loss, $C_2(F)$ is the total investment cost of the FACTS devices and $C(T)$ is the operational cost of the system.

The active and reactive nodal power should be within the limits as:

$$P_{ni}^{min} \leqslant P_{ni} \leqslant P_{ni}^{max}$$

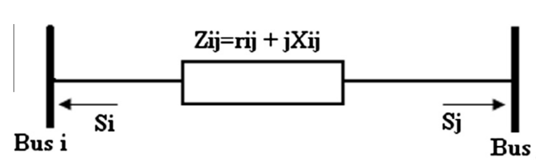


**Fig. 2.** TCSC injection model.