
Optimal Placement of FACTS Devices: A Review

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Abstract

This review paper presents a bibliographical survey and review on Optimization Techniques for location of Flexible AC Transmission System in Power Systems. Flexible AC Transmission System (FACTS) are the electronic based compensation devices that may be helpful in meeting out requirement of electrical power up to some extent in a deregulated market. In this review Thyristor-Controlled Series Compensation (TCSC), Static Synchronous Compensator (STATCOM), Unified Power Flow Controller (UPFC), Unified Power Quality Conditioner (UPQC), Interline Power Flow Controller (IPFC) are considered to place optimally. The review is limited to optimal placement the of the FACTS devices for control strategy and stability of the power system networks for maximum benefits. The optimal placement of different FACTS devices with the different criteria of the objective function is considered for discussion.

Keywords

FACTS Devices; TCSC; STATCOM; UPFC; Optimal FACTS Placement.

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Introduction

The ever increasing demand of electrical power and its quality are necessary in almost all the power systems but generation is limited due to high the fuel consumption and other constraints. The implementation of FACTS devices has the advantage of the reduction in reactive power supply, harmonics of source current. Also, it also helps in reduced bus voltage sag and swells, and power loss etc. Due to huge investment optimal location and sizing of FACTS devices are a must. In deregulated environment the unplanned power exchange to the main power grid may results in unhealthy to the system. The stability margins of the power system may be reduced due to this and rising the risk of cascading outages or an unstable system. In the deregulated power system poor system stability and voltage level are evident. In order to provide stable, reliable, efficient and secure operation of power system the placement of the FACTS devices should be optimal.

The optimal placement of the FACTS devices are provide increased real power flow in the system without increasing complexity in existing power generation network. Without incorporating additional lines the FACTS devices are capable to improve the system security by maintaining the voltage regulation, reducing the congestion by maintaining power flow regulation. The installation of the FACTS devices keeps the system stress free by maintaining voltage and the power regulation. The aim of the paper is to place of the FACTS devices optimally in the transmission system.

Constraints of Transmission System and FACTS Technonolgy

Transmission System Constraints

The installation of the optimal FACTS devices in the transmission network allow the system to work very near to its stability and the thermal limits. The AC power system have inherent power stability as the power flow between the lines are dependent on the receiving and the sending end voltages. For a lossless line, which has the sending end voltage V_1 , receiving end voltage V_2 , θ_1 and θ_2 are the phase angles of the sending and receiving end respectively. The power flow equation can be given as

$$P = \frac{V_1 V_2}{X} \sin(\theta_1 - \theta_2) \quad (1)$$

Where X is the reactance of the line.

In the deregulated power generation environment the generation would be dependent to the environmental condition, fuel availability, economical conditions etc. At the same time the load also varies as per the climatic conditions, day timing, expansion etc. The variation in both the load and the generation may create a system security problem. For example the power system is operating very close to either its thermal or the stability limit, and even small sudden change in the system load or generation occurs, may result in power swings and even cascaded tripping. The increased load may upset the voltage regulation of the system and may lead to congestion also.

The various constrains that has to be take care are

1. Transient Stability and voltage Limit
2. Dynamic Voltage Limit
3. Power Transfer Limit at Steady State
4. System Oscillation Damping limit

5. Thermal Limit
6. Short Circuit Current limit

These constraints would be applicable to almost all the transmission lines. Some transmission lines of the system would have two or more of the above limits reached. Increasing power delivery by the power generation units can solve all these problems. But, there is economical and the environmental constraints involve in increasing the power generation units. In spite of increasing power generation units, FACTS devices may be used. These devices can control the real and the reactive power dynamically, may provide the support to the system to a major extent. The conventional devices which are mostly used for the power system problems are series capacitor, switched reactor and capacitor, the voltage regulation, phase shifting transformer which are used for the angle variation, synchronous condenser for controlling the voltage.

FACTS Technology

Thermal loading limits are highly important for transmission lines. At the same time transmission stability limits, voltage limits and the loop flows are also take care not to reach the thermal limits^[41,42,43].

FACTS devices are power electronic based technology and are capable to the power flow in the power system. The benefits of use of the FACTS devices:

1. The dynamic characteristics of FACTS devices help in rapid real and reactive power control
2. The reduced in congestion the network
3. The continuous compensation can be achieved
4. System voltage profile and power loss can be controlled
5. The problem of lines overloading can be minimized with voltage compensation
6. Transient stability can be improved

As can be seen from equation (1) the FACTS devices control various parameters of systems like the impedance, the power angles in order to contain the voltage and power regulations.

Widely used FACTS devices to control the voltage in the transmission lines are Static VAR Compensator (SVC) and STATCOM. TCSC controls the impedance, Thyristor Controlled Phase Shifting Transformer (TCPST) Controls angle. The other FACTS devices which can control above parameters are UPFC, IPFC and Static Synchronous Series Controller (SSSC).

Different installation issues of the FACTS devices are the cost, sizing of the devices and different control during transient and steady state.

The FACTS devices and its controlling action on the variables which would control the transient limits, voltage limits are as given below. The topology of STATCOM is as given below.

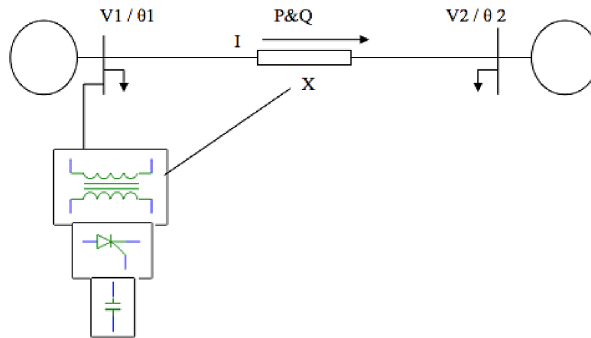


Figure 1. STATCOM Topology

The STATCOM topology in Figure 1 explains that the term is controlled in the equation (1), which would be the voltage compensation. This indirectly compensates the reactive power as the reactive power can be defined as in equation (2).

$$P = \frac{(V_1 - V_2)V_1}{X} \cos(\theta_1 - \theta_2) \quad (2)$$

It can be seen from the equation (2) that if there were any difference in the voltage of the sending and the receiving end then the reactive power would increase with increase in the difference. Thus the voltage limit that has to be compensated by the STATCOM should be designed accordingly.

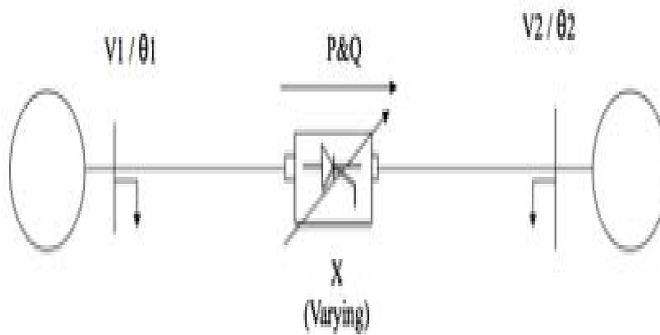


Figure 2. TCSC Topology

The TCSC topology defines that in the two bus system considered the value of the reactance varies in order to control the power flow by line impedance compensation.

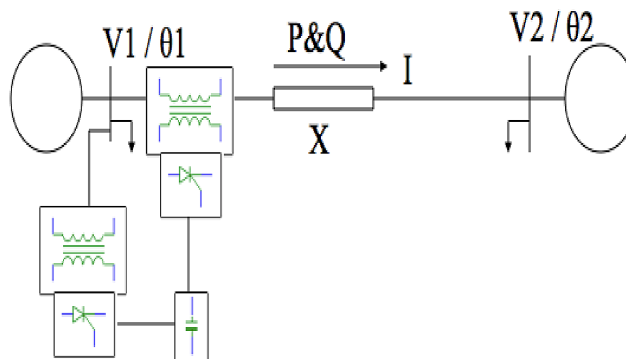


Figure 3. UPFC Topology

Figure 3. UPFC Topology The overall power flow of the transmission system is controlled by the use of regulating the bus voltage and also injecting the voltage in series to the line.

Objectives of Placement of FACTS Devices

The optimal location of the FACTS device is an important issue while the installation of the devices is considered

The important factors that are considered while its placement in the power system constraints are.

1. Minimization of power loss in the transmission system.
2. Minimization of reactive power loss.
3. Congestion management.
4. Improved Power transfer capability.

Optimal Placement of FACTS Devices –A Review

Meta Heuristic Algorithms like Genetic Algorithm (GA), Particle Swarm Optimization (PSO), and Harmonic Search Algorithm (HSA) are optimization techniques used for the placement of the FACTS devices. The optimal placement, selection and sizing of device in order to minimize both the generation cost and FACTS devices cost using the HSA and GA algorithms^[1]. Power transfer capability and the voltage regulation are considered placement of both devices the TCSC and the SSSC under both normal conditions and contingency condition. A comparative study has been explored between TCSC and SSSC^[2]. In order to increase the profit of the private supplier in the deregulated environment and also to improve load ability the optimal location of FACTS has been find out^[3]. Voltage stability improvement and the power loss minimization are considered as the objective function^[4], for placement of FACTS devices using the GA. Enhancing the security of the power system during contingency or minimizing the bus voltage deviation by placement of UPFC has been carried out in implementing PSO and GA algorithm^[5]. The placement of multi FACTS SVC and TCSC on the transmission line to improve the voltage stability using the GA^[6]. For Optimal Power Flow (OPF) placement of the FACTS has been

done considering as the constraint by device-using GA, for a improved power flow without violation of the limits^[7]. Sensitivity analysis and the extended equal area criterion have been implemented as the objective function for the optimal placement of FACTS devices in order to improve the voltage as well as transient stability^[8]. In the deregulated environment, optimal location, size and number of FACTS devices has been considered to be optimized in the power system^[9].

For improved Power system load ability, by optimal placing multiple TCSC devices using optimization algorithm PSO and GA^{[11][12][14][18]}. The controlling active and the reactive power and voltage regulation of the system placement of UPFC devices using GA has been carried out^[13]. The power quality management including load ability and the loss minimization has been is carried out in^[15]. The optimal placement of UPFC using linear and the nonlinear load^[16]. The total cost including the generation cost and the cost of FACTS has been considered for placement of FACTS devices with GA as the optimization algorithm^[17].

The forecasting of reactive power for the large transmission system with private power suppliers has been considered using GA^[19,20].

In^[21] the Tabu Search (TS), Simulated Annealing (SA) and the GA methods has been explored for the optimal placement of TCSC, TCVR, TCPST, SVC and UPFC. Implementation of all these algorithms provided the same results for the placement of the FACTS devices. In order to compare the increase in load ability when single and multiple FACTS devices has been used^[22]. The collapse point has been analyzed by using the continuous power flow applied on the power system by placing the FACTS devices using the GA^[23]. For the shunt compensating devices while used in the long distance transmission lines it has been found that the optimal placement of the FACTS devices lie at the center of the transmission line. In^[24] it has been proved that the shunt FACTS device when placed slightly before or after the center the power transfer capability has improved.

In^[25] the sensitivity analysis has been implemented for considering the reactance that the TCSC has to bear while the optimal location of the TCSC has been carried out. The optimal placement of TCSC and SVC has been carried out in order to enhance the power transfer capability with sensitivity approach^[26].

The Meta heuristic methods have been combined in order to get the better convergence to improve the computational and the optimization benefits. The placement of STATCOM has been done using hybrid Meta heuristic algorithm combining the Ant Colony Optimization (ACO) and GA. The optimization has the objective of finding the best location and capacity of the STATCOM device^[27]. The ACO got improved convergence while the GA is fused with the ACO.

A Multi-objective Fuzzy (MOF) has been combined with the GA in order to find a optimal location and size of shunt FACTS controllers. The objective is to increase the distance to saddle node bifurcation and improve bus voltage profile^[28]. The hybrid algorithm that combines the TS and the SA approach has been implemented to get the optimal location for multiple FACTS devices^[29].

The multi objective particle swarm optimization for optimal allocation of the SVC by the mixed continuous discrete multi objective optimization problem^[30]. Enhancement in stability, reduction real power loss voltage deviation is observed.

For the lower cost of installation and system stability as the optimization constraints the PSO has been used on SVC, TCSC and UPFC devices.^[31]

The Time Varying Accelerating Constant (TVAC) has been implemented for the optimization, which gives an optimal location, and size of the STATCOM^[32].

PSO algorithm has been compared for ideal location and sizing of STATCOM, PSO-TVAC has been found better in providing computation speed and solution quality^[32]. Continuous Power flow for placement of the UPFC to increase load ability has been discussed^[33].

Mixed Integer programming with PSO for optimizing the power flow^[34], Honey Bee Mating Optimization (HMBO) for parameter tuning of the TCSC and SVC placement^[35], Non –Dominated Sorting Improved Harmony Search (NSHS) with crowding distance strategy^[36], Line Flow Overload Sensitivity Index (LFOSI) based optimization for TCSC controller^[37], Graphical User Interface with GA as the optimization technique for the placement in order to choose the different FACTS devices like SVC, UPFC, TCPST placing in multiple locations are developed with different constraints user defined^[38].

MATLAB implementation of PSO optimized FACTS device with and without wind energy to enhance load ability and minimize in power loss has been discussed and compared^[39] Congestion management using Differential Evolution (DE) with Fuzzy logic controller^[40].

Conclusion

The review of different optimal Placement methods has been presented available in literature. The different series and shunt FACTS devices like SVC, STATCOM, IPFC, TCSC UPFC, with different objective function has been placed optimally with different algorithms. The different hybrid optimization algorithm for the optimal placement of FACTS devices has also been discussed in the transmission system are discussed.

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