Ph.D Summary Report

On

Optimal Placement of FACTS Devices Using AI Tools

Submitted

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INTRODUCTION

Deregulated power systems poses many advantages over the vertically integrated power systems, but the deregulated power systems are facing some issues like congestion management, available transfer capability, market price, transmission pricing, voltage collapse. Moreover changes in system operating conditions like increase in load or any fault in the system affects the dynamic and transient stability of the system. Introduction of FACTS devices has thrown new opportunities to control power flow and maximizing the usable capacity of existing transmission lines. Various FACTS devices like Static Var Compensator (SVC), Thyristor Controlled Series Converter (TCSC), Unified Power Flow controller (UPFC) and Static Synchronous Compensator (STATCOM) are being effectively used for voltage and power control. However optimal location of these devices is very important for the full utilization of these devices as the cost of installation is very high.

The issue of optimal location of FACTS devices has been extensively brainstormed and several strategies have been used and implemented. Conventional optimization methods, which have been used for solving the reactive power optimization, are linear programming, nonlinear programming, mixed integer programming, decomposition method, etc. However, these conventional methods can only be lead to a local minimum and most of them cannot deal with integer problem. On the other hand, Evolutionary algorithms are the computer based problem solving systems which are computational models of evolutionary processes as key elements in design and implementation. Tabu Search (TS), Simulated Annealing (SA), Genetic algorithm (GA) and Particle Swarm Optimization (PSO). All these techniques can effectively optimize power system performance with single objective and multi-objectives. Optimal location of FACTS devices using these heuristic techniques has been discussed and implemented thoroughly. These techniques find the optimal location for voltage stability, loss minimization and to increase power flow. However the problem arises in case of multi-objective optimization. All the techniques discussed above can effectively handle single objective optimization but as far as more objectives are concerned these fail to reach to global minima. So multi-objective optimization techniques have to be used to overcome the complexities. Various
multi-objective optimization techniques are implemented to solve a power system multi-objective optimization problem to find the optimal location; these are Multi-objective Genetic Algorithm (MOGA), Multi-objective Particle Swarm Optimization (MOPSO), Strength Pareto Evolutionary Technique (SPEA) etc. These evolutionary techniques handle the problem as a truly multi-objective problem to find the optimal location.

**SCOPE OF THE WORK**

Optimal location of FACTS devices for static, dynamic and transient stability enhancement has been discussed in literature. Various techniques to find the optimal location for static voltage stability has been presented like PV curve, stability indices, and modal analysis. All these methods determine the weakest bus and critical line of the system for optimal location of these devices for IEEE standard systems. Various approaches have been discussed for dynamic and transient stability enhancements which are based on Eigen value analysis, trajectory sensitivity analysis. Various types of controllers for damping low frequency oscillations like PI controller, fuzzy controller, neural based controller has been presented in many of the research papers. Tuning of the PI controllers for finding out the optimal parameters values for transient stability improvement has been presented and simulated. Various optimization techniques like tabu search, Simulated annealing, Genetic algorithm, Particle swarm Optimization(PSO) etc. have been presented to find the optimal location of FACTS devices for power system stability. These optimization techniques are based on the formulation of objective function and then optimal value is calculated based on the fitness. Optimal location of FACTS devices using Genetic algorithm and PSO has been discussed for single objective optimization where the optimization is done taking single objective into consideration. Optimal location problem is a multi-objective optimization problem where no of objective functions are to be optimized like power flow control, congestion management, and improvement in voltage stability, prevention of voltage collapse, loss minimization and also the installation cost minimization of FACTS devices. In case of multi-objective optimization where two or more objectives have to be optimized simultaneously numbers of solution arise because the trade off between the conflicting results is important. The need of evolutionary techniques arises to solve these types of multi-objective problems
Various techniques have been presented for multi-objective optimization like Non Dominated Sorting Algorithm (NSGA), Multi-objective Particle Swarm Optimization (MOPSO), Strength Pareto Evolutionary Technique (SPEA). These techniques handle the problem as truly multi-objective problem where pareto optimal front is obtained and a population of solution is obtained instead of single solution. Various evolutionary techniques to find the optimal location, type and size of FACTS devices optimizing two objectives have been presented. Still there was a need to solve a multi-objective optimization problem to seek the optimal location of FACTS devices taking all the objectives into mind for power system security and stability which includes the objective functions related to maximize the power flow in the line, to relieve the overloaded lines, to maintain the bus voltages within limits, to maximize voltage stability and security of the system, to minimize the system losses and to reducing the installation cost of FACTS devices. Scope of the thesis is to formulate a multi-objective function taking all the objectives for power system stability and security to find the optimal location and rating of FACTS devices using SPEA technique with fuzzy framework to obtain the best solution out of pareto set formed.

**WORK ACCOMPLISHED DURING RESEARCH PROGRAM**

In this thesis, optimal location of FACTS devices has been determined for steady state dynamic and transient stability enhancement of power system. Optimal location for Steady state voltage stability improvement has been determined using line indices (VCPI and FVSI). The weakest bus and the critical line with respect to a bus is determined and it is observed that by placing the FACTS devices at that location loadability margin has been enhanced considerably and hence the voltage stability of the system is improved. Optimal location of FACTS controllers based on eigen value analysis for dynamic stability enhancement has been presented. Eigen values are calculated for different locations of FACTS devices and optimal location is determined based on eigen values. Optimal location of FACTS devices for transient stability enhancement has been demonstrated based on critical clearing time. A three phase to ground fault is created at different buses and critical clearing time (CCT) is determined for different locations of SVC. In order to improve the power system performance, a multi-objective function is
formulated taking the four objectives into consideration i.e. line loading maximization, voltage stability maximization, loss minimization and installation cost minimization and optimal location is determined considering all the objectives to improve the system performance. Initially all the objectives are optimized individually using Genetic Algorithm for IEEE 14 bus system and IEEE 30 bus system and then the optimal location problem is handled as a truly multi-objective optimization problem taking all the objectives concurrently using Strength Pareto Evolutionary Algorithm to find the optimal location, type and rating of FACTS devices for power system security and stability. The results obtained show that the proposed approach optimize all the objectives effectively and gives the optimal solution.

**ORGANIZATION OF THE THESIS**

The work has been divided into following Chapters.

**Chapter 1:** The Chapter, “Introduction,” emphasizes on the basic introduction about the power system stability, impact of FACTS devices on steady state, dynamic and transient stability and the techniques to determine the optimal location for power system performance enhancement. The chapter also discusses the scope of the work.

**Chapter 2:** The Chapter, “Literature Review,” deals with the work already done for the optimal location of FACTS devices for steady state, dynamic and transient stability enhancement using various optimization techniques.

**Chapter 3:** The Chapter, “Steady State Voltage Stability Enhancement of Power System by Proper Placement of FACTS devices”, describes the optimal location of FACTS devices for voltage stability using PV curves and two stability indices, Voltage Collapse Proximity Index (VCPI) and Fast Voltage Stability Index (FVSI). The most critical line with respect to a bus and the weakest bus is determined. It is observed that by optimally placing FACTS devices at that location loadability of the system has been increased considerably leading to steady state voltage stability.
Chapter 4: The Chapter, “Optimal location of FACTS devices Using Dynamic stability Analysis,” determines the optimal location of SVC based on Eigen-Value analysis for dynamic stability enhancement. A three phase to ground fault is created and loading is increased, eigen values are obtained for different locations of SVC and based on eigen values optimal location is determined for a particular fault location.

Chapter 5: The Chapter, “Optimal location of FACTS devices for transient stability enhancement based on critical clearing time (CCT)”, deals with the determination of optimal location of FACTS devices based on critical clearing time for transient stability improvement. A three phase to ground fault is created at different locations near to generators and away from the generators and CCT is observed for different loading conditions. It has been observed that location of SVC changes with the fault location.

Chapter 6: The chapter, “Optimal Location of FACTS devices Using Genetic Algorithm,” emphasizes on the application of genetic algorithm to find the optimal location, type and rating of FACTS devices for single objective optimization to improve power system steady state performance. Four objectives namely line loading maximization, voltage stability maximization, loss minimization and total installation cost minimization have been considered individually for optimization and optimal location has been determined. Congestion management is also done with the help of FACTS devices.

Chapter 7: The Chapter, “Optimal Location of FACTS devices Using Evolutionary Algorithm for Multi-Objective Optimization,” focuses on the Multi-objective optimization using Evolutionary technique to find the optimal location of FACTS devices. The four objectives discussed in chapter 6 have been optimized taking two, three and four objectives simultaneously and it is observed that objective function values are optimized as compared to single objective optimization.

Chapter 8: The Chapter, “Conclusion and future scope of the Work,” emphasizes on the conclusion of the work and its possible future extensions.
CONCLUSION

Optimal location of FACTS devices for steady state, dynamic and transient stability enhancement has been presented for an IEEE 14 bus system. The stability indices are used to identify the critical line referred to a bus. It is observed that optimal location of UPFC and SVC in the system increases the loadability margin and reduces the line stability indices at critical lines increasing the steady state system stability. Voltage profile is also improved at all the weak buses. Continuation Power Flow is done using PSAT/MATLAB software. Optimal location of SVC for dynamic stability enhancement has been determined with eigen-value analysis. Time domain simulation has been done by placing SVC at the optimal location and the results show that proper placement of SVC enhances the steady state, dynamic and transient stability of the system by reducing the settling time of the oscillations. Transient stability enhancement by optimal placement of SVC based on Critical Clearing Time is presented. A three phase to ground fault is created at different buses near to the generating units and far away from the generators. CCT is determined for different locations of SVC for different loading conditions. It is observed that the fault near to the generators must be cleared rapidly for power system stability. Further it is concluded that with the increase in load CCT reduces thus making the system unstable and also location of SVC is also dependent on the fault location. The location where the CCT value is the greatest is the optimal location for SVC at particular location of fault. It is observed that by placing SVC at that location, oscillations are damped out quickly leading to the enhancement of transient stability of power system making the system stable for longer duration. From the results obtained from the dynamic and transient stability enhancement of power system, it is concluded that the optimal location is same for both dynamic and transient stability enhancement for a particular location of fault. Optimal location of SVC and TCSC has been determined using genetic algorithm taking four objectives into consideration i.e. line loading maximization, voltage stability maximization, real power losses minimization and installation cost minimization. The simulations are done on an IEEE 14 bus system and IEEE 30 bus system. A Matlab coding has been developed. Initially all the objectives are optimized individually using GA and it is observed that taking one objective into consideration other objective is not
optimized and the results are conflicting so all the objectives are optimized simultaneously using Strength Pareto Evolutionary Algorithm (SPEA) to obtain the optimal solution. The objectives are optimized taking two at a time, three and all the four objectives at a time. It is observed from the results that with multi-objective optimization the objective function values have considerably improved from the base values and results have appreciably improved than single objective optimization.

MAJOR REFERENCES


