Applications of FACTS devices in Improving Stability in Power System

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Abstract: This paper presents exhaustive review of various concept of voltage instability, main causes of voltage instability, classification of voltage stability, dynamic and static voltage stability analysis techniques, modeling, shortcomings, in power systems environments. This paper presents a comprehensive review on the research and developments in the power system stability enhancement using FACTS damping controllers. Several technical issues related to FACTS installations have been highlighted and performance comparison of different FACTS controllers has been discussed. In addition, some of the utility experience, real-world installations, and semiconductor technology development have been reviewed and summarized. Applications the EPS equipped with a decentralized modular secondary voltage and reactive power control based on artificial neural network (ANN) is presented. The ANNs were trained on optimal power flows (OPF).

I. INTRODUCTION

Since the development of interconnection of large electric power systems, there have been spontaneous system oscillations at very low frequencies in order of 0.2–3.0 Hz. Once started, they would continue for a long period of time. In some cases, they continue to grow causing system separation due to the lack of damping of the mechanical modes [1;2]. In the past three decades, power system stabilizers (PSSs) have been extensively used to increase the system damping for low frequency oscillations. However, there have been problems experienced with PSSs over the years of operation. Some of these were due to the limited capability of PSS, in damping only local and not inter area modes of oscillations. In addition, PSSs can cause great variations in the voltage profile under severe disturbances and they may even result in leading power factor operation and losing system stability [13]. This situation has necessitated a review of the traditional power system concepts and practices to achieve a larger stability margin, greater operating flexibility, and better utilization of existing power systems.

Flexible AC transmission systems (FACTS) have gained a great interest during the last few years, due to recent advances in power electronics. FACTS devices have been mainly used for solving various power system steady state control problems such as voltage regulation, power flow control, and transfer capability enhancement. Generally, it is not cost-effective to install FACTS devices for the sole purpose of power system stability enhancement. In this work, the current status of power system stability enhancement using FACTS controllers was discussed and reviewed. This paper is organized as follows. The development and research interest of FACTS is presented in Section 2. Section 3 discusses the potential of the first generation of FACTS devices to enhance the low frequency stability while the potential of the second generation is discussed in Section 4. Section 5 highlights some important issues in FACTS installations such as location, feedback signals, coordination among different control schemes, and performance comparison.

II. FACTS DEVICES

A. Overview

In the late 1980s, the Electric Power Research Institute (EPRI) formulated the vision of the Flexible AC Transmission Systems (FACTS) in which various power-electronics based controllers regulate power flow and transmission voltage and mitigate dynamic disturbances. Generally, the main objectives of FACTS are to increase the useable transmission capacity of lines and control power flow over designated transmission routes. There are two generations for realization of power electronics-based FACTS controllers, the first generation employs conventional thyristor-switched capacitors and reactors, and quadrature tap changing transformers, the second generation employs gate turn-off (GTO) thyristor-switched converters as voltage

source converters (VSCs). The first generation has resulted in the Static Var Compensator (SVC), the Thyristor- Controlled Series Capacitor (TCSC), and the Thyristor-Controlled Phase Shifter (TCPS) [10,11]. The second generation has produced the Static Synchronous Compensator (STATCOM), the Static Synchronous Series Compensator (SSSC), the Unified Power Flow Controller (UPFC), and the Interline Power Flow Controller (IPFC) [12–15]. The two groups of FACTS controllers have distinctly different operating and performance characteristics. The thyristor controlled group employs capacitor and reactor banks with fast solid-state switches in traditional shunt or series circuit arrangements.

The thyristor switches control the on and off periods of the fixed capacitor and reactor banks and thereby realize a variable reactive impedance. Except for losses, they cannot exchange real power with the system. The voltage source converter (VSC) type FACTS controller group employs self-commutated DC to AC converters, using GTO thyristors, which can internally generate capacitive and inductive reactive power for transmission line compensation, without the use of capacitor or reactor banks. The converter with energy storage device can also exchange real power with the system, in addition to the independently controllable reactive power. The VSC can be used uniformly to control transmission line voltage, impedance, and angle by providing reactive shunt compensation, series compensation, and phase shifting, or to control directly the real and reactive power flow in the line [15]. In the paper, a framework of a new SVQC concept that could be applied to Slovenian power system is envisioned. The Slovenian power system has a peak load of 1700 MW and comprises some 30 generators.

They operate decomposed in separate generating companies, which could besides energy offer the power system ancillary services as well. In the decomposed power system regarding generators, it would be of advantage to conceive a secondary voltage and reactive power control system adapted to their organization structure. The paper addresses an extreme decomposition of the secondary voltage control system adapted to the above goals. The SQVC-s should be attached to the generator or to the generator-transformer block and adapt the reference voltage for the primary excitation controller to the power system requirements and limitations. That way, the generating companies would obtain a powerful tool to enter the ancillary services market regarding the power system voltage support and reactive power.

III. CLASSIFICATION OF FACTS CONTROLLERS
A. Sensitivity Based Methods
There are various sensitivity based methods such as a modal or Eigen-value analysis, and index method. An Eigen value analysis approach has been addressed for modeling and simulation of SVC and TCSC to study their limits on

maximum load ability point in [11]. A new methodology has been addressed for the solution of voltage stability when a contingency has occurred, using coordinated control of FACTS devices located in different areas of a power system.An analysis of the initial conditions to determine the voltage stability margins and a contingency analysis to determine the critical nodes and the voltage variations are conducted. The response is carried out by the coordination of multiple type FACTS controllers, which compensate the reactive power, improving the voltage stability margin of the critical modes. A new coordination synthesis method using as an Eigen value sensitivity analysis and linear programming has been addressed for simultaneous able to select the generators to which the PSS can be effectively applied and to synthesize the adequate transfer function of the PSSs for these generators.

The An Eigen value sensitivity based analysis approach has been addressed for control coordination of series and shunt FACTS controllers in a multi-machine power system for series and shunt FACTS controllers considered are SVC, TCSC and SVC-TCSC combination, its analysis approach has been also addressed for design and coordinate multiple stabilizers in order to enhance the electro-mechanical transient behavior of power systems. A frequency response technique has been used for coordinated design of under-excitation limiters and power system stabilizers (PSS) in power system for enhance the electromechanical damping of power system oscillations. A problem of interest in the power industry is the mitigation of power system oscillations. These oscillations are related to the dynamics of system power transfer and often exhibit poor damping, with utilities increasing power exchange over a fixed network, the use of new and existing equipment in the transmission system for damping these oscillations is being considered in several literatures. A non-linear technique has been proposed for robust nonlinear coordinated excitation and SVC control for power systems for enhance the transient stability of the power systems.

A new method has been proposed for the design of power system controllers aimed at damping out electro-mechanical oscillations used for applied to the design of both PSS for synchronous generators and supplementary signals associated to other damping sources. Voltage collapse problems in power systems have been a permanent concern for the industry, as several major blackouts throughout the world have been directly associated to this phenomenon. Many analysis methodologies have been proposed and are currently used for the study of this problem, as recently reported in several literatures The coordinated power flow control should address the following points such as elimination of interaction between FACTS controllers, ensuring system stability of the control process, security transmission system for both pre and post fault, and achieving optimal and economic power flow. A new method has been suggested for the potential application of coordinated secondary voltage

control by multiple FACTS voltage controllers in eliminatingvoltage violations in power system contingencies in order to achieve more efficient voltage regulation in a power system.

The coordinated secondary voltage control is assigned to the SVCs and Static Compensators (STATCOM) in order to

eliminate voltage violations in power system contingencies. A new methodology has been proposed for decentralized optimal power flow control for overlapping area in power systems for the enhancement of the system security. The controllers considered for coordination are voltage regulators, PSS, speed governors, main and auxiliary controllers of HVDC converters, and main and auxiliary controllers of SVC. A sensitivity based analysis approach is used to find out an inter coupling between a variation of set points of different FACTS devices and a volume of load shedding with a variation of active power flow in transmission lines. A systematic procedure for the synthesis of a Supplementary Damping Controller (SDC) for Static VAR Compensator (SVC) for a wide range of operating conditions is used for testing in multi-machine power systems to enhance the damping of the inter-area oscillations, providing robust stability and good performance characteristics both in frequency domain and time domain. The secure operation of power systems requires the application of robust controllers, such as Power System Stabilizers (PSS), to provide sufficient damping at all credible operating conditions. A design method that explicitly considers both the coordination and the robustness issues has been proposed for coordinated design of power system stabilizers and supplementary control of FACTS devices to enhance the robustness of the control scheme for drastic changes in the operating condition.

B. Optimization Based Methods

This section reviews the optimal placement of FACTS controllers based on various optimization techniques such as a linear and quadratic programming, non-linear optimization programming, integer and mixed integer optimization programming, and dynamic optimization programming. A Benders Decomposition technique has been used for these solutions. A mixed integer optimization programming algorithm has been proposed for allocation of FACTS controllers in power system for security enhancement against voltage collapse and corrective controls, where the control effects by the devices to be installed are evaluated together with the other controls such as load shedding in contingencies to compute an optimal VAR planning, a mixed integer non-linear optimization programming algorithm is used for determine the type, optimal number, optimal location of the TCSC for load ability and voltage stability enhancement in deregulated electricity markets. A mixed integer optimization programming algorithm has been used for optimal location of TCSC in a power system. Chang and Huang et al. showed that a hybrid optimization programming algorithm for optimal placement of SVC for voltage stability

reinforcement.

C. Artificial Intelligence Based Techniques

This section reviews the optimal placement of FACTS controllers based on various Artificial Intelligence based techniques such as a Genetic Algorithm (GA), Expert System (ES), Artificial Neural Network (ANN), Tabu Search Optimization (TSO), Ant Colony Optimization (ACO) algorithm, Simulated Annealing (SA) approach, ParticleSwarm Optimization (PSO) algorithm and Fuzzy Logic basedapproach. A genetic algorithm has been addressed for optimal location of phase shifters in the French network to reduce the flows in heavily loaded lines, resulting in an increased loadability of the network and a reduced cost of production. A genetic algorithm has been addressed for optimal location of multiple type FACTS controllers in a power system. The optimization are performed on three parameters; the location of the devices, their types and their values. The system loadability is applied as measure of power system performance. Four different kinds of FACTS controllers are used as models for steady state studies: TCSC, TCPST, Thyristor Controlled Voltage Regulator (TCVR) and SVC in order to minimizing the overall system cost, which comprises of generation cost and investment cost of FACTS controllers [17]. A stochastic searching algorithm called as genetic algorithm has been proposed for optimal placementof static VAR compensator for enhancing voltage stability in [18]. Reference [19], genetic algorithm (GA) and particle swarm optimization (PSO) has been proposed for optimal location and parameter setting of UPFC for enhancing power system security under single contingencies.

The VAR planning problem involves the determination of location and sizes of new compensators considering contingencies and voltage collapse problems in a power system. The Genetic Algorithm (GA) and PSO techniques for optimal location and parameter setting of TCSC to improve the power transfer capability, reduce active power losses, improve stabilities of the power network, and decrease the cost of power production and to fulfill the other control requirements by controlling the power flow in multi machine power system network. In a Particle Swarm Optimization (PSO) technique has been addressed for optimal location of FACTS controllers such as TCSC, SVC, and UPFC considering system loadability and cost of installation. In the theory of the normal forms of algorithm has been addressed for the SVC allocation in multi machine power system for power system voltage stability enhancement. In a knowledge and algorithm based approach is used to VAR planning in a transmission system. The VAR planning problem involves the determination of location and sizes of new compensators considering contingencies and voltage collapse problems in a power system. Applications of FACTS to power system stability in particular have been carried out using same databases.

The results of this survey are shown in Figure 1, Figure 2

It was found that the ratio of FACTS applications to the stability study with respect to other power system studies is more than60% in general. This reflects clearly the increasing interest to the different FACTS controllers as potential solutions for power system stability enhancement problem. It is also clear that the interest in the 2nd generation of FACTS has been drastically increased while the interest in the 1st generation was decreased. The potential of FACTS controllers to enhance power system stability has been discussed, where a comprehensive analysis of damping of

power system electromechanical oscillations using FACTS was presented. The damping torque contributed by FACTS devices, where several important points have been analyzed and confirmed through simulations.
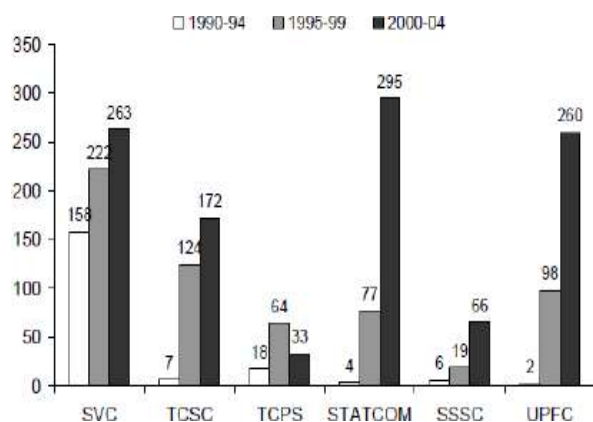

Fig1. Statistics for FACTS applications to different power system studies
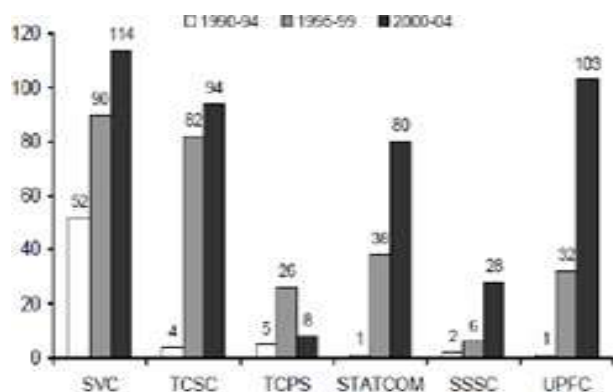

Fig2. Statistics for FACTS applications to power system stability.

IV. NEURAL NETWORKS IN POWER SYSTEMS

Several papers dealing with ANN applications in power systems are briefly described in the subsections below. They have been grouped with respect to the following application areas: Static and dynamic security assessment, transient stability assessment, identification, modeling and prediction, control, load forecasting and fault diagnosis. This work referenced by the most of the authors in ANNs and power systems, dealt with the assessment of dynamic security. An adaptive pattern recognition approach based on a feed

forward neural net with a back propagation learning scheme was implemented to synthesize the Critical Clearing Time (CCT). Simulations results showed how autonomous feature discovery was carried out in terms of direct system measurements instead of pragmatic features based on the engineering understanding of the problem. In this case unsupervised and supervised learning paradigms in tandem were used. The stability boundary was constructed using tangent hyper surfaces. ANNs were used to determine the unknown coefficients of the hyper surfaces independently of operating conditions. Numerical results and comparisons between CCT analytically obtained and ANN-basedindicated that this approach provides quick assessment ofpower system security in 1993, the authors (joined with Lee) presented a methodology applying ANN to carry out real-time stability analysis of power systems. Near-term transient stability of the system, mid-term and long-term dynamic security analysis were performed. The first one dealt with whether the system can return to steady-state, and the second one dealt with the manner of the final state is reached. They utilized the Kohonen Neural Net as classifier of power system states.

The relation among the number of clusters, the number of neurons and the size of the power systems were investigated. Simulation results demonstrated the successful generalization property of the ANN. The important feature is that correct assessment was obtained not only when the net was queried with an element of the training set of data, but also at other operating conditions. The input stimulus for the net was contingency parameters such as transmission line status, machine excitations and generation level. Feed forward ANNs were used. This generator was connected to a large power system. As input to the net, real power, power factor and power system stabilizer parameters were used. The output was a discrete signal: dynamically stable or unstable. The proposed ANN was compared with the multilayer feed forward with a back propagation-momentum learning algorithm. It is said that the proposed ANN is more suitable for discrete output values.

V. RESULTS & DISCUSSIONS

The control criterion of the ANN SVQC balances the voltage profile of the power system, while at the same time diminishes the active and reactive power losses. To evaluate the influence of the proposed ANN SVQC scheme we have focused on the power system operation economy and its security. The ANN SVQC-controlled power system voltage profile (labeled as ANN) was compared to that of the base power system operating state in which the voltage references were preset to a fixed value. These power system states also arose immediately after the disturbance and before the ANN

Fig3.Voltage profiles in a healthy system case 30 base cases.

SVQC reacted. They have been labeled as base case. The two voltage profiles were in turn compared to the optimal voltage
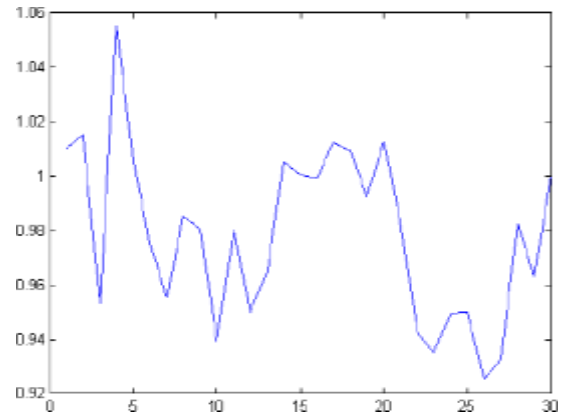
profile, calculated with a help of the OPF. For this purpose, the following criteria were selected: voltage profile of the entire EPS for a selected operating state and voltage histogram for the test set and a selected node.

proposed ANN based scheme exerts also favorable influence on power system operation economy and security the voltage
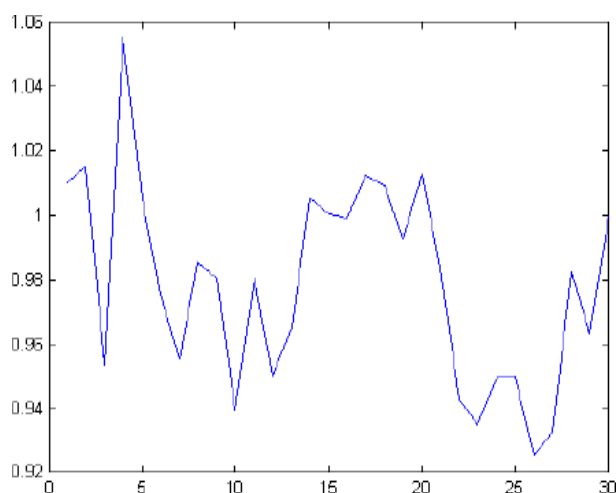

Fig 4.Voltage profiles in a healthy system case 30 opf

The statistical evaluation of the ANN SVQC-s performance regarding active power losses may be seen in Fig. 3. It shows significant improvement over the base case, whereas frequency distribution of the ANN results resembles the OPF distribution. A similar conclusion can be drawn for the ANN improvement of reactive power losses when compared to OPF results in Fig. 4. A power system voltage profile presents voltage levels for all the nodes and for a selected operating state. The first ten data points depict generator nodes while the rest are load buses. On the other hand, voltage histograms offer the frequency of certain voltages in a selected power system bus for all the operating states in the entire test set. In both cases, the comparison comprises base cases, operating states the ANN SVQC action and optimal solutions. Through combining both methods it is possible to correlate the events in the power system and the ANN SVQC corrective actions, which in turn leads to security assessment.

VI. CONCLUSION

In this review, the current status of power system stability enhancement using FACTS controllers was discussed and scrutinized. The essential features of FACTS controllers and their potential to enhance system stability was addressed. The location and feedback signals used for design of FACTS-based damping controllers were discussed. The coordination problem among different control schemes was also considered. Performance comparison of different FACTS controllers has been reviewed. The likely future direction of FACTS technology, especially in restructured power systems, was discussed as well. In the paper, a proposal of a decentralized secondary voltage control framework using ANN that was developed for a Slovenian power system is outlined. In addition to standard SVQC objectives, the

Controller. CIGRE Technical Brochure, 1998.

profile during normal operation without outages is governed. Sub-optimally using only ANN SVQC. At the same time, the operation remains economical, as the active and reactive power losses are sub-optimal and comparable to those obtained via OPF and improved when compared to base case.

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