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Review on the Research and Developments of FACTS Controller in Improving Power System Stability

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ABSTRACT: Now-a-days it is becoming very difficult to fully utilize the existing transmission system assets due to various reasons, such as environmental legislation, capital investment, rights of ways issues, construction cost of new lines, deregulation policies, etc. Electric utilities are now forced to operate their system in such a way that makes better utilization of existing transmission facilities. Flexible AC Transmission System (FACTS) controllers, based on the rapid development of power electronics technology, have been proposed in recent years for better utilization of existing transmission facilities. With the development of FACTS technique, it becomes possible to increase the power flow controllability and enhance power system's stability. This paper presents a comprehensive review on the research and developments FACTS controller in improving power system stability.

I. INTRODUCTION

A linear optimal controller is designed to implement multiple variable series compensations in transmission networks of interconnected power systems. The proposed controller was utilised to damp interarea oscillations and improve power system damping.[1]the model of a power system installed with a unified power flow controller (UPFC) was presented.

A STATCOM, UPFC, and convertible static compensator were discussed [4]. The installed FACTS controllers have provided new possibilities and unprecedented flexibility aiming at maximizing the utilization of transmission assets efficiently and reliably. Mishra, et.al. presented a simple hybrid fuzzy logic proportional plus conventional integral controller for FACTS devices in a multi-machine power system [2]. This controller was designed by using an incremental fuzzy logic controller in place of a proportional term in a conventional PI controller and provides a wide variation of controller gains in a nonlinear manner. This controller is well suited to series connected FACTS devices like UPFC, TCSC and TCPST, etc., in damping multi-modal oscillations in a multi-machine environment.

Dingguo *et.al.* [5] presentd the power system stability problem involving the regular generator-angle stability and load-driven voltage instability. Transient stabilization of simplified power systems equipped with the FACTS device, the thyristor-controlled series capacitor was studied with consideration of unknown loads. With some off-line time-optimal trajectories computed based on the switching-times-variation method some technique were developed to synthesize robust near-time-optimal neural controllers.

A new fuzzy proportional action was introduced to enhance the performance of output feedback controllers. This fuzzy system has a simple structure and acts as a nonlinear function so that the gain of the controller was not constant but changes according to the error value [16].

Khatami et.al. Presented a linearized model of a SMIB power system with a TCSC controller was developed. The designed fuzzy c-means clustering TCSCcontroller adjusts control signal by appropriately processing of the input signals, and provides an efficient damping [32].

In a linearized model of a single machine-infinite bus with a unified power flow controller was developed [26].

Optimal location of multi-type FACTS deviceswas investigated using a genetic algorithm [7] in a power system. In the paper the optimizations were performed on three parameters: the location of the devices, their types and their values. Four different kinds of FACTS controllers were used and modeled for steady-state studies: TCSC, TCPST, TCVR and SVC.

Tuning, performance and interactions of PSS and FACTS controllers in a test power system was discussed.[9] The controllers are placed in the system to control electromechanical oscillations (Hopf bifurcations) and the corresponding gains are tuned to observe their effect on oscillatory modes and overall system performance.

Cai, *et al.,* presented the simultaneous coordinated tuning of the FACTS (flexible AC transmission systems) POD power oscillation damping) controller and the conventional PSS (power system stabilizer) controllers in multimachine power systems. Using the linearized system model and the parameter-constrained nonlinear optimization algorithm, interactionsamong FACTS controller and PSS controlle rs were considered [11]. Coordinated control of PSS and FACTS devices to improve the inter-area mode oscillation at minimum cost was proposed. The approach presented enables us to allocate a set of TCSCs to improve the stability of interconnected power systems. The proposed approach determines the location of controllers by making use of eigenvalue analysis, active power sensitivity and linear quadratic regulator [12].

The inter-area mode low frequency oscillations by analyzing the phenomena in Nashville area of the Tennessee Valley Authority (TVA) system studied was studied. The active power is controlled to damp the low frequency oscillation while the reactive power is controlled to keep the local bus voltage at a constant level [13].

Nguyen, et.al. Presented an approach for designing coordinated controllers of power system stabilizers (PSSs) and FACTS devices stabilizers for enhancing small-disturbance stability. The control co-ordination problem is formulated as a constrained optimization with eigenvalue-based objective function without any need for the linear approximation by which the sensitivities of eigenvalues of state matrix to controller parameters are formed. The eigenvalue-eigenvector equations are used as the equality constraints in the optimization. The controller parameters bounds are formulated as the inequality constraints [14].

Using the linearized system model and the parameter-constrained nonlinear optimization algorithm ,inter actions among FACTS controller and PSS controllers the simultaneous coordinated tuning proposed in multi-machine power systems [15].

STATCOM is a FACTS controller that is used in power systems to regulate the line voltage, enhance the power transmission capacity and extend the transient stability margin. STATCOM is conventionally realized by a voltage-source converter; however, being a current injection device, its performance can be improved when realized by a current-source converter (CSC) that can generate a controllable current directly at its output terminals [18]. An approach for designing coordinated controllers of power system stabilizers (PSSs) and FACTS devices stabilizers for enhancing small-disturbance stability was presented. The control co-ordination problem is formulated as a constrained optimization with eigen value-based objective function without any need for the linear approximation by which the sensitivities of eigen values of state matrix to controller parameters are formed.

The eigen value-eigenvector equations are used as the equality constraints in the optimization. The controller parameters bounds are formulated as the inequality constraints. Simulation results show that the controller design approach is able to provide better damping and small-disturbance stability performance [20].

The main objective of this paper was to investigate the enhancement of power system stability via coordinated design of Thyristor Controlled Series Compensation (TCSC) and Power System Stabilizers (PSSs) in multi machine power system. The design problem of the proposed controllers was formulated as an optimization problem. Using the developed linearized power system model, the particle swarm optimization (PSO) algorithm is employed to search for optimal controllers' parameters settings that maximize the minimum damping ratio of all system eigenvalues. The proposed controller is evaluated on a multi machine power system. The nonlinear simulation results and eigenvalue analysis show the effectiveness of the proposed controller in damping power system oscillations [21].

Using objective function which maximizes the function, the total damping ratios of the system were optimized and dynamic stability of the system would be improved. In this method all the operation conditions are considered. Simulation results for a large system and different operation conditions of the system shows that this method has a good efficiency and can be effective solution for this problem in a large system. This method can be effective for the coordinating of multi-controllers in large power systems [22].

An optimal procedure for optimal control co-ordination of controllers of power system stabilizers (PSSs) and FACTS devices were developed for improving small- disturbance stability, particularly the stability of inter-area modes, in multi-machine power systems. The control coordination problem was formulated as a constrained optimization by which the objective function formed from selected eigenvalues of the power systems state matrix was minimized [24].

Kumar *et.al.,* has been proposed a controllability index to find the optimal location of the FACTS controllers to damp out the inter-area mode of oscillations. Three types of FACTS controllers have been considered, which include static var compensator, thyristor-controlled series compensator and unified power flow controller. The proposed controllability index was based on the relative participation of the parameters of FACTS controllers to the critical mode. [25]

A simple approach of computing the controllability indices has been proposed, which combines the linearised differential algebraic equation model of the power system and the FACTS output equations. The placements of FACTS controllers have been obtained for the base case as well as for the critical contingency cases. The effectiveness of the proposed method is demonstrated on New England 39-bus system and 16-machine, 68-bus system [25].

Jyothsna et.al. Presented A Multi-Objective Evolutionary Programming (MOEP) based approach to Static Synchronous Series Compensator (SSSC). The multi-objective optimization problem is formulated to the design problem of SSSC, in which the system transient stability is improved by minimizing several system behavior measure criterions. Then, MOEP was used to design the Flexible Alternating Current Transmission Systems (FACTS) controller parameters. The usefulness of the proposed control scheme was demonstrated with a three machine nine bus power system under different fault conditions. By minimizing the time-domain based multi objective function, in which the deviations in the oscillatory rotor angle, rotor speed and accelerating power of the generator are involved, stability performance of the system is greatly improved [27].

A new, simple approach for modeling and assessing the operation and response of the multiline voltage-source controller (VSC)-based flexible ac transmission system controllers, namely the generalized interline power-flow controller (GIPFC) and the interline power-flow controller (IPFC), was presented in this paper. The model and the analysis developed were based on the converters' power balance method which makes use of the - orthogonal coordinates to thereafter present a direct solution for these controllers through a quadratic equation [28].

Modeling of converter-based controllers when two or more VSCs are coupled to a dc link (e.g., unified power-flow controller (UPFC), interline power-flow controller, and a generalized unified power-flow controller) was presented. This approach also allows efficient implementation of various VSC operating limits, where one or more VSCs were loaded to their rated capacity [29

Nguyen, et.al. Developed a new design procedure for online control coordination which leads to adaptive power system stabilizers (PSSs) and/or supplementary damping controllers of flexible ac transmission system (FACTS) devices for enhancing the stability of the electromechanical modes in a multimachine power system. The controller parameters are adaptive to the changes in system operating condition and/or configuration. Central to the design is the use of a neural network synthesized to give in its output layer the optimal controller parameters adaptive to system operating condition and configuration.

A novel feature of the neural-adaptive controller was that of representing the system configuration by a reduced nodal impedance matrix which is input to the neural network. Only power network nodes with direct connections to generators and FACTS devices are retained in the reduced nodal impedance matrix. The system operating condition is represented in terms of the measured generator power loadings, which are also input to the neural network [31].

Guo Cheng *et.al.,* deals with the simultaneous coordinated tuning of the power system stabilizer (PSS) controllers and the flexible ac transmission system (FACTS) power oscillation damping controllers in power system. A new particle swarm optimization approach was proposed for the design of optimal PSS and FACTS power oscillation damping (POD).[33]

Xiaoyan Bian et.al. Presented an application of probabilistic theory to coordinated design of power system stabilizers (PSSs) and FACTS controllers, taking static VAR system (SVC) as an example. The aim is to enhance the damping of multi electromechanical modes in a multimachine system over a large and pre-specified set of operating conditions. A probabilistic eigenvalue-based objective function for coordinated synthesis of PSS and SVC controller parameters are then proposed. The effectiveness of the proposed controllers was demonstrated on an 8-machine system [34].

Bati, A.F." Investigated the ability of STATCOM in damping power systems oscillations. The optimal pole shifting (OPS) technique using Genetic Algorithm would be applied in designing STATCOM damping controller. The dynamic interaction of STATCOMcontroller was analyzed [40].

A systematic approach for designing of Static var Compensator (SVC) based damping controllers for damping of low frequency oscillations in a power system investigated in Ref [38]. Detailed investigation have been carried out considering two controllers like Power System Stabilizer (PSS) controller and Power Oscillation Damping (POD) controller under variation of mechanical disturbances (P_m) which provides robust performance for single machine infinite bus (SMIB) power system.[38]

Authors presented a global tuning procedure for FACTS power oscillation damping (POD) and power system stabilizers (PSSs) in a multi-machine power system using real coded genetic algorithm. The stabilizer's gains were obtained through the minimization of an objective function based on the damping ratio. The proposed controllers were simultaneously designed and they have provided a coordinated control action and a satisfactory performance for the power system, as shown in the results [39].

Kanojia, S.Set.al. proposed the controllers, were designed to coordinate two control inputs: Voltage of the injection bus and capacitor voltage of the STATCOM, to improve the transient stability of a SMIB system and multimachine system. The STATCOM controller namely conventional PI controller. The power oscillations damping (POD) control and power system stabilizer (PSS) and their coordinated action with proposed controllers were tested [41].

Belwanshi *et.al.* Presented a new concept Fuzzy logic based supplementary controller is installed with Interline Power Flow Controller [IPFC] to damp low frequency oscillations.

IPFC is a new concept of the Flexible AC Transmission system controller for series compensation with the unique capability of power flow of multiple transmission lines [42]. Talebi *et al.* presented the linearized model of synchronous machine (Heffron-Philips) connected to infinite bus (Single Machine-Infinite Bus: SMIB) with UPFC. and also in order to damp LFO, adaptive neuro-fuzzycontroller for UPFC was designed and simulated [43].

Abido *et. .al.* presented the enhancement of power system stability via Thyristor Controlled Series Compensation (TCSC), in a two area interconnected power systems. The design problem of the proposed controllers was formulated as an optimization problem. Using the developed linearized power system model, the particle swarm optimization (PSO) algorithm is employed to search for optimal controllers' parameters settings that maximize the minimum damping ratio of all system eigenvalues [44].

Miotto, *et.al*. presented an analysis of the dynamic performance of a multimachine power system in the presence of device Flexible AC Transmission Systems (FACTS) acting in conjunction with robust controllers. Model Power Sensitivity (PSM) was used to represent the multimachine power system. The design of the controllers Power System Stabilizers (PSS) and Power Oscillation Damping (POD) was performed so simultaneous and coordinated, and was based on robust control techniques. The method is structured in the form of linear matrix inequalities (LMIs). The controllers are found by solving the set of LMIs that describe the control problem [45].

Atalik, et.al. a fully digital controller based on multiple digital signal processor (DSP) and field-programmable gate array (FPGA) boards has been proposed for parallel-operated cascaded multilevel converters (CMC) used in flexible AC transmission system (FACTS) applications. The proposed system was composed of a DSP-based mastercontroller in combination with a multiple number of slave DSP boards, FPGA boards, microcontrollers, a programmable logic controller (PLC), an industrial computer, and their peripherals in interaction. Intercommunication of these digital controllers was achieved mainly through fiber-optic links, via synchronous serial data link wherever a high-speed, full duplex communication was needed, and via asynchronous serial communication interface wherever relatively slow communication speed was required [46].

CONCLUSION

In this review, the status of power system stability improvement using FACTS controllers was discussed.

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