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Coordinated Control Techniques of FACTS Devices in Power System

Vinita Roy[1], Jignesh rasadiya[2]

Research Scholar, Electrical Engineering, Rajasthan Institute of Engineering and Technology, Jaipur
[1] Associate professor, Dept. of Electrical Engineering, Rajasthan Institute of Engineering and Technology, Jaipur

Abstract— This paper presents an extensive survey on the existing cases, system studies and assessment techniques to help system planners understand the underlying mechanism of diverse interactions among multiple FACTS controllers and develop coordinated control schemes for preventing or mitigating any harmful interactions. This paper presents in-depth review of several literatures in regarding with interaction problems and various techniques for coordinated control between PSS and FACTS controllers or FACTS to FACTS controllers in power system environments. It may also be effective in transient stability improvement, power oscillations damping and balancing power flow in parallel lines. It has been noticed that adverse interactions among multiple FACTS controllers may occur when they are not properly coordinated with each other and other slowly acting system equipment.

Keywords— Interaction, Coordinated Control, FACTS Devices,

INTRODUCTION

On the other hand, FACTS devices are a powerful technology that can solve many outstanding problems in power systems. They provide the opportunity to influence power flows and voltages and therefore are able to enhance the system security, e.g. by improving the voltage profile or increasing the transfer capacity of a system without the need of new lines. FA CTS devices can be used to control power flows. Today‘s power grids are driven closer to their transfer capacities due to the increased consumption and power transfers, endangering the security of the system. Provided that they are located at optimal locations, FACTS devices can be applied to achieve the optimal power flow without any constraint violation. Therefore, they can be used to achieve power system economic operation by means of increasing the utilization of the lowest cost generation. FACTS types and their locations should be chosen according to their contributions to the general objective of power system economic generation and dispatching [1].

It is understood that the FACTS controller will normally be equipped with higher order controllers such as power swing damping controller, Sub Synchronous Resonance (SSR) damping controller etc. Still to develop an insight, the FACTS controller is assumed to be equipped with simple PI controller only [2].

The likely interactions have been classified into different frequency ranges. The various interactions that can potentially occur between the different FACTS controllers, as well as between FACTS and PSS‘s or HVDC controllers, in power system environments.

Inter-area oscillations with frequencies ranging from 0.1 to 1.8 Hz are common problems in large extended power systems. They are usually spontaneous; that is, they can be initiated by small disturbances, such as changes in load that take place continually. There are several methods proposed in literature for coordination of FACTS controllers from voltage stability/ small signal stability viewpoint [3] .Various other techniques for coordination of FACTS controllers in power system networks such as fuzzy coordination method [4], genetic algorithms method [5] have been used for

coordination of FACTS controllers in power system networks. There are several interaction problems between FACTS controllers or FA CTS to PSS‘s from voltage stability/ s mall signal stability viewpoint are review in literature [2].

Inter-area oscillations are associated with the linear response of the system and represent natural modes of oscillation. Inter area oscillations [7] can also be associated with the nonlinear response of the system. They appear when the system is subjected to large disturbances, such as sudden and large load change or system faults. Inter-area oscillations involve oscillations of a group of generators in one area swinging against a group of generators in another area. Such oscillations are very harmful and may cause a total breakdown in the power transfer, especially when there are weakly coupled transmission lines in the system carrying large loads.

INTERACTIO N O F FACTS DEVICES

An interaction phenomenon between dynamic loads and FACTS controllers in power systems. Different power system configurations have been studied (power system with/without dynamic loads, uncertainty and variation of dynamic load parameters). Two methods have been proposed in [6] to solve this problem. The first one based, on sensitivity and residues techniques, takes into account the uncertain character of dynamic loads to compute the most efficient phase compensation for low frequency oscillations damping. The second approach consists on designing a robust damping controller by LMI (Linear Matrix Inequalities) techniques in the aim of guaranteeing a certain degree of stability and performances of the FACTS controllers in presence of dynamic loads uncertainties.

Type of Interactions of FACTS Controllers:

1>Multiple FACTS Controllers of a Similar Type

2>Multiple FACTS Controllers of a Dissimilar Type

3>Multiple FACTS Controllers and HVDC Converter Controllers

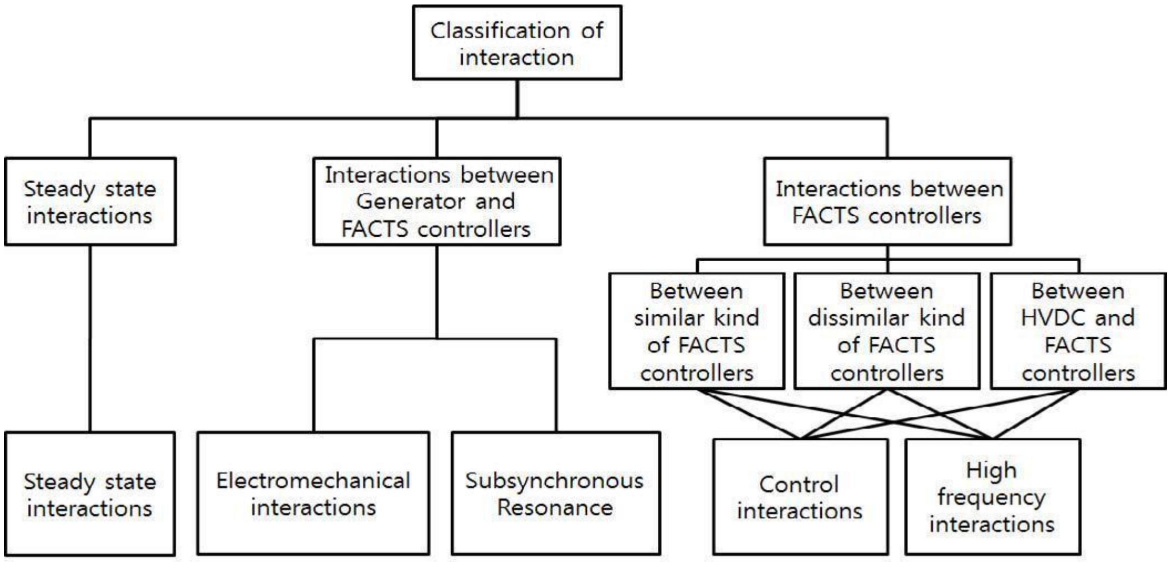

Fig. 1 Classification of Interactions

Because of the many combinations that are possible, an urgent need arises for power systems to have the controls of their various dynamic controllers coordinated. The term coordinated implies that the controllers have tuned simultaneously to effect an overall positive improvement of the control scheme in [24], [25].

Control interactions are known to cause oscillatory stability problem as detailed in [7]. As suggested in [7], the oscillations may be generally categorized into the following four; local plant mode oscillations, inter area mode oscillations, torsional mode oscillations, and control mode oscillations. These categories may further be classified in terms of interaction characteristics. Note that this is just one way of classifications for the convenience of systematic analysis. For the convenience of analysis, three categories of interactions as follows: 1. steady state interactions, 2. generator or machine-related oscillations, and 3. interactions between FACTS controllers. Steady state interactions as similarly described in [8] focus on the system response in the steady state operating space for which control dynamics are not incorporated.

Interactions between FACTS controllers may be included in control mode oscillations [8]. Control mode oscillations include interactions between controllers of generating units and FACTS as well. It is interesting to notice that controller interactions are classified into five types by frequency ranges in [9]: steady state interactions, electromechanical interactions, control interactions, sub-synchronous resonance interactions, and high frequency interactions. Each suggested category of this paper may fit in these five categories as follows:

Steady state interactions:

Steady state interactions
Generator or mach ine-related interactions:
Electro mechanical interactions

Subsynchronous resonance (SSR) interactions
Interactions between FACTS controllers:
Control interactions

High frequency interactions

The frequency ranges of the different control interactions have been classification as follows [24].

A. 0 Hz for Steady State Interactions

Steady-state interactions between different controllers (FACTS-FACTS or FACTS-HVDC) occur between their system – related controls.

They are steady state in nature and do not involve any controller dynamics. These interactions are related to issues such as the stability limits of steady-state voltage and steady- state power; included are evaluations of the adequacy of reactive power support at buses, system strength and so on.

B. 0-3/5 Hz for Electro-Mechanical Oscillations

Electromechanical-oscillation interactions between FACTS controllers also involve synchronous generators, compensator machines, and associated power-system stabilizer controls. The oscillations include local mode oscillations, typically in the range of 0.8-2 Hz, and inter-area mode oscillations, typically in range of 0.2-0.8 Hz.

C. 2-15 Hz for Small-Signal or Control Oscillations

Control interactions between individual FACTS controllers and the network or between FACTS controllers and HVDC links may lead to the onset of oscillations in the range of 2-15 Hz (the range may even extend to 30 Hz). These oscillations are largely dependent on the network strength and the choice of FACTS controllers parameters [11].

D. 10-50/60 Hz for Sub Synchronous Resonance (SSR) Interactions

Sub synchronous oscillation may be caused by the interaction between the generator torsional system and the series compensated transmission lines [24].

METHO DS FO R COORDINATION

The essential design features of multiple FACTS controllers that can ensure secure operation with sufficient damp ing over a wide range of power system operating conditions are presented in [11]. The term coordination does not imply centralized control; rather, it imp lies the simultaneous tuning of the FACTS controllers to attain an effective, positive improvement of the overall control scheme. It is understood that each controller relies primarily on measurements of locally available quantities and acts independently on local FACTS equipment. In a practical power system, there could be number of FA CTS devices installed, which may cause interaction between them. This is more likely to be true in foreseeable future in the deregulated environment. These multiple FA CTS devices have the potential to interact with each other. This interaction may either deteriorate or enhance system stability depending upon the chosen controls and their placement. Hence there is a need to study the interaction between the FACTS controllers [2].

An optimal procedure for designing co -ordinated controllers of power system stabilizer and flexible ac transmission system devices is developed [12] for achieving and enhancing small-disturbance stability in multi-machine power

systems. A constrained optimizat ion approach is applied for minimizing an objective function formed from selected eigenvalues of the power systems state matrix. The eigenvalue–eigenvector equations associated with the selected modes form a set of equality constraints in the optimizat ion. There is no need for any standard eigenvalue calculation routines, and the use of sparse Jacobian matrix in the case of large system for forming the eigenvalue –eigenvector equations leads to the sparsity formulation.

A new method has been proposed [13] based on the method of inequalities for the coordinated synthesis of Power System Stabilizer (PSS) parameters in multi-machine power systems in order to enhance overall system s mall signal stability. Since the coordination and control of PSS‘s is a Pareto-optimization problem, a comprehensive list of design objectives has been presented in terms of a set of inequalities.

A method is developed for the simultaneous coordination of power system stabilizers (PSSs) and FACTS device stabilizers (FDSs) in order to enhance the damping of the rotor modes of oscillat ion in a mult i machine system. The proposed coordination scheme emp loys linear programming [14]. A global tuning procedure for FACTS Device Stabilizers (FDS) and Power System Stabilizers (PSS) in a mult imachine power system using a parameter -constrained non-linear optimization algorith m imp lementer in a simu lation program. This algorithm deals with such an optimizat ion problem by solving a sequential quadratic programming using the dual algorithm [17].

A new method has been proposed based on the method of inequalities for the coordinated synthesis of Power System Stabilizer (PSS) parameters in multi-machine power systems in order to enhance overall system small signal stability. Since the coordination and control of PSS's is a Pareto-optimization problem, a comprehensive list of design objectives has been presented in terms of a set of inequalities. To solve these inequalities, Genetic Algorithms have been applied to determine the PSS parameters. [24]

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 [15]. The response is carried out by the coordination of mu ltip le-type FACTS devices, which compensate the reactive power, improving the voltage stability margin of the critical nodes. a new methodology to improve the voltage stability margin in a power system after a contingency has occurred, using coordinated control strategy of multiple type FACTS devices. This strategy is based on a fast response of FACTS devices [15] to inject and change the direction of power flow, in order to compensate reactive power to the critical nodes.

A new fuzzy proportional action is introduced to enhance the performance of output feedback controllers. This fuzzy system has a simp le structure and acts as a nonlinear function so that the gain of the controller is not constant but changes according to the error value. To show the effectiveness of the proposed

fuzzy output feedback controller co mputer simulations for coordination application of two thyristor controlled series capacitor-based stabilisers are performed [16].

The coordinated design of multiple FA CTS supplementary damping controllers to improve system small-signal stability, a BMI-based (Bi-Linear Matrix Index) multi-objective multi-model system approach is formulated to solve the robust damping control problem [18]. Two-step method is proposed to determine controller variables. Regional pole placement and control effort optimization are set as the control objectives. An SVC and a TCSC damping controller are designed sequentially with minimized decoupling effort.

In [19], it mainly controls the voltage stability in adjacent areas of power system, analyzes the characteristics of different voltage stability problems, and consider the characteristics and control laws of medium and long -term voltage stability and transient voltage stability, then puts forward a multi-objective voltage stability coordinated control strategy that based on SVC (Static Var Compensator) and TCSC (Thyristor Controlled Series Compensation). Besides, the paper designs appropriate structure controllers of SVC and TCSC, and verifies the control strategy which can be an effective solution to controlling needs and achieve coordination of different voltage control functions in simulation platform.

A supervisory controller based on Optimal Power Flow (OPF) with multiple objectives is derived in [20], in order to avoid congestion, provide secure transmission and minimize active power losses. The contributions of SVC, TCSC and TCPST in this coordinated control and the achieved improvements compared with the case where no FACTS devices are in operation are demonstrated.

A combination of the TCSC (Thyristor Controlled Series Capacitor) and SVC (Static Var Compensator) installation to achieve superior performance for enhancing the inter-area stability of a 2-area interconnected 4-machine system is presented in [21]. The developed scheme employs a damping controller which coordinates two measurement signals to control the TCSC and SVC. The coordinated control method is based on the application of projective controls.

A bacterial-foraging oriented by particle swarm optimization (BFPSO) algorithm is employed to design the coordinated parameters of power system stabilizer (PSS) and static VAR compensator (SVC). In [22], nonlinear model o f power system and SVC is used to design parameters of PSS and SVC. For this purpose, this design problem is firstly converted to an optimization problem and then the BF-PSO algorithm is used to solve it. Simulations are carried out on four machine 11 bus power system in MATLA B software. The results confirm the efficiency of the proposed method for stabilizing the power system oscillations.

In [23], sensitivity analysis is used to determine the area on which the FACTS device has considerable influence and then only this limited area is included in the Optimal Power Flow control. If there are several devices placed in the same system, the areas assigned to these devices might overlap indicating mutual influences. Therefore, a coordination of the control entities is needed in order to avoid conflicting behavior of the devices raising the issue of Multi-Area Control. Here, the method based on Approximate Newton Directions [23] is extended for the case of overlapping areas which are determined by sensitivity analysis.

Four broad categories of techniques have been proposed in [26] for co- ordinations of multiple FACTS controllers.

1) Conventional Methods for Coordination

-Newton's Approach.
-Successive Quadratic Programming (SQP) for NFL problems.

2) *Sensitivity Based Methods for Coordination*

-Eigen values Analysis Based Controller Optimization and Coordination Techniques.

-Index Methods

2) *Control Design Based Methodology for Coordination*

-Linear Control Method

-Non-Linear Control Methods

3) *Optimization and Artificial Intelligence Based Techniques*

-Fuzzy Coordination of Multiple FACTS Controllers

-Genetic Algorithms (GA) for Coordination of Multiple FA CTS Controllers

CONCLUS ION

Modal analysis can clearly indicate whether the system is stable or not at the given operating mode. Many researchers tried to attempt review on various optimization based methods which are used for coordination control of FACTS devices and optimal placement of FACTS controllers in multi-machine power system to achieve significant improvement in operating parameters such reactive power, real power, voltage magnitudes and phase angles at all nodes of the network of the system but not mentioned the actual practical installation of various FACTS devices in power system in the world and its applications . In addition, the participation factors clearly define areas prone to voltage instability and indicate elements which are important to improve the system voltage stability most effectively. The main function of FACTS controller coordination is to provide additional degree of freedom to control power flows and voltages in existing power system at key location of network. There are numbers of approaches proposed in literatures for coordination of multiple FACTS controllers in multi-machine power systems from different operating conditions viewpoint .This paper presents a review of several literatures in regarding with interaction problems and various techniques for coordinated control between PSS and FA CTS controllers or FA CTS to FACTS controllers in multi-machine power system environments .

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