CHAPTER 2

CONCEPT OF SMART POWER FLOW CONTROL

2.1 INTRODUCTION

This chapter presents a novel intelligent concept of smart power flow control for the interconnected power system. The concept is based on knowledge domain states mapping and best suited under dynamical changing system operating conditions. Till date various algorithms have been reported for the design of power flow controllers such as adaptive techniques, neural network and other intelligent optimization techniques, however these algorithms have some limitation due to on-going operational shift not mapped in offline training. As online conditions change and offline conditions based control design does not fit in respective parametric set, the performance of the controller so designed may be relatively poor. Under such a situation, the controller parametric tuning may be inadequate in operational domain of the on-going system dynamics and may result in power oscillations. This situation can be addressed with the design of an intelligent power control capable of mapping perturbation in control design criterion. The on-going perturbation forms the basis of respective cluster of knowledge domain, and based on this the controller parameters may be effectively designed for effective oscillation damping. This can be termed as knowledge domain for a specific perturbation (states representing system dynamical changes) and the controller parameter selection/controller selection in order to match system requirements optimally. The present work deals with knowledge domain states mapping concept, in which initial parameters of controllers are tuned offline for most of the expected system operating conditions (may be based on historical shift observed earlier through system changes/operators experiences in utility control centre), then stored in respective knowledge domain (cluster of perturbation). As and when in online condition some operating condition occurs close to knowledge domain database (the tuned operating conditions), controller retrieves the best-suited parameters from knowledge domain to stabilize the system, however if the operating conditions occur other than the stored condition, knowledge domain will be updated with newer shift over and above old one and corresponding knowledge domain database is updated. So with the occurrence of new operational shift each time/interval, dynamical knowledge domain is updated and therefore, the control structure so derived with updated parameters base, the controller performance is improved. Proposed concept also includes the hierarchical control structure modularly with the concept of controller range up-gradation by way of inducting either new set of parameters or new controller in addition to the existing controller for larger domain coverage and thus ensures effective oscillation damping with inference mechanism, well tracking the real-time variation with intelligent automation. The method can be understood by the following points.

2.2 INFORMATION OF DYNAMIC VARYING STATES

Power systems have major states which represent the behavior of a dynamic varying system. These states are the voltages, currents, frequency and phase angles. Deviation in these states defines the stability and security of the complete power network. If they are more towards the oscillatory nature with increase in the amplitude then power systems are having some problems in terms of generation load mismatch or some contingency. Retuning controller's parameters ensure the fast response with proper modulation of desired real and reactive power in the network which helps to minimize the system oscillation and increase the damping in network. The proposed concept is based on the small signal stability model by deriving the complete power system in the state space framework. In this model generator's state variables such as angular speed, phase angle, internal voltage and the voltage across field windings have been defined which either can be measured directly (ω and E_{fd}) or synthesized (δ and E'_q). Controller design is based on all these state variables. When any perturbation occurs in the system in terms of change in loading pattern or change in length of transmission line, dynamic response of these states variables varies and they may violate their threshold limits. The states which violate or tend to violate the desired system response quickly under any perturbation are termed as vulnerable states and by identifying these states, control action is initiated based on state predominant concept. So the control action linked with the dynamic change in the system state variables help to regulate the entire power network and improves the stability.

In this model, these dynamical state variables can be derived by states space modeling with the final state matrix of the system. The internal voltage of the generator is not directly measurable, but can be computed using the machine reactance (available from the design data), terminal voltage and line current (which can be measured in real time) whereas the voltage across the field winding is applied externally via a DC source and can be easily measured. However, while realizing this control structure for real-time application, the signaling with PMUs installed at generator terminal will be more effective for multi-area power control due to GPS time framework. The evolving power control technology with PMUs will not only provide time stamped data but also may be linked with multi-controller architecture in large network structure for effective control injection and ensuring power oscillation damping at the earliest. This will not only enhance the generator life but also reduced switchyard components failure and afterward effects. PMUs are also being deployed in the transmission system for measurement of angle and magnitude of three phase voltage and current, angular separation, frequency and Rate of Change of Frequency (ROCOF) at nearly every 40 milliseconds in load dispatch centers. Control activation can be done based on the data received from these signals using parallel processing algorithms based control architecture using knowledge domain states mapping concept.

2.3 KNOWLEDGE DOMAIN (KD) STRUCTURE DEVELOPMENT

Knowledge domain is defined by the setting of control parameters of all controllers connected in the network for various system operating conditions. It also sets the range of each tuned control parameters for some specific operating conditions for which systems state variables are well within their desired limits and damp out oscillations quickly. Controller performance depends on the system operating conditions. The tuned control parameters for an operating point are capable of rejecting perturbation within acceptable operational shifts as control design criterion. However, if tuned controller parameters range is violated due to additional perturbation, then controller parameters up-gradation may be realized from one set point to another set point from knowledge domain to match the required control efforts for additional perturbation in order to prevent system failure. If one controller is not enough to damp the oscillation in the system, then another controller will be inducted (as a supplementary control) depending upon the operational shift straight away that modulates power flow as required and thus damps system oscillations as quickly as possible.

Knowledge domain is developed offline by heuristic optimization algorithms. This has been developed by running the optimization techniques under different system operating conditions and finding the optimal parameters of all the controllers connected in the network. In this research work three well-known optimization techniques (PSO, FA and GSA) have been used to develop the knowledge domain structure for all the controllers. Figure 2.1 shows the structure of knowledge domain concept for smart power flow control. C11, C12,…C1N are the setting of controller 1 with stamping with their operating points O11,O12,…O1N. Similarly C21, C22,…C2K are the setting of combined controller 1 and 2 with reference to the system operating points

O21,O22,….O2K. The notation is same for combination of controller 1, 2 and 3. With ξ is the extra control effort required for the controller to shift its position from one point to another point. C1, C2 and C3 represent the controller 1, 2 and 3.

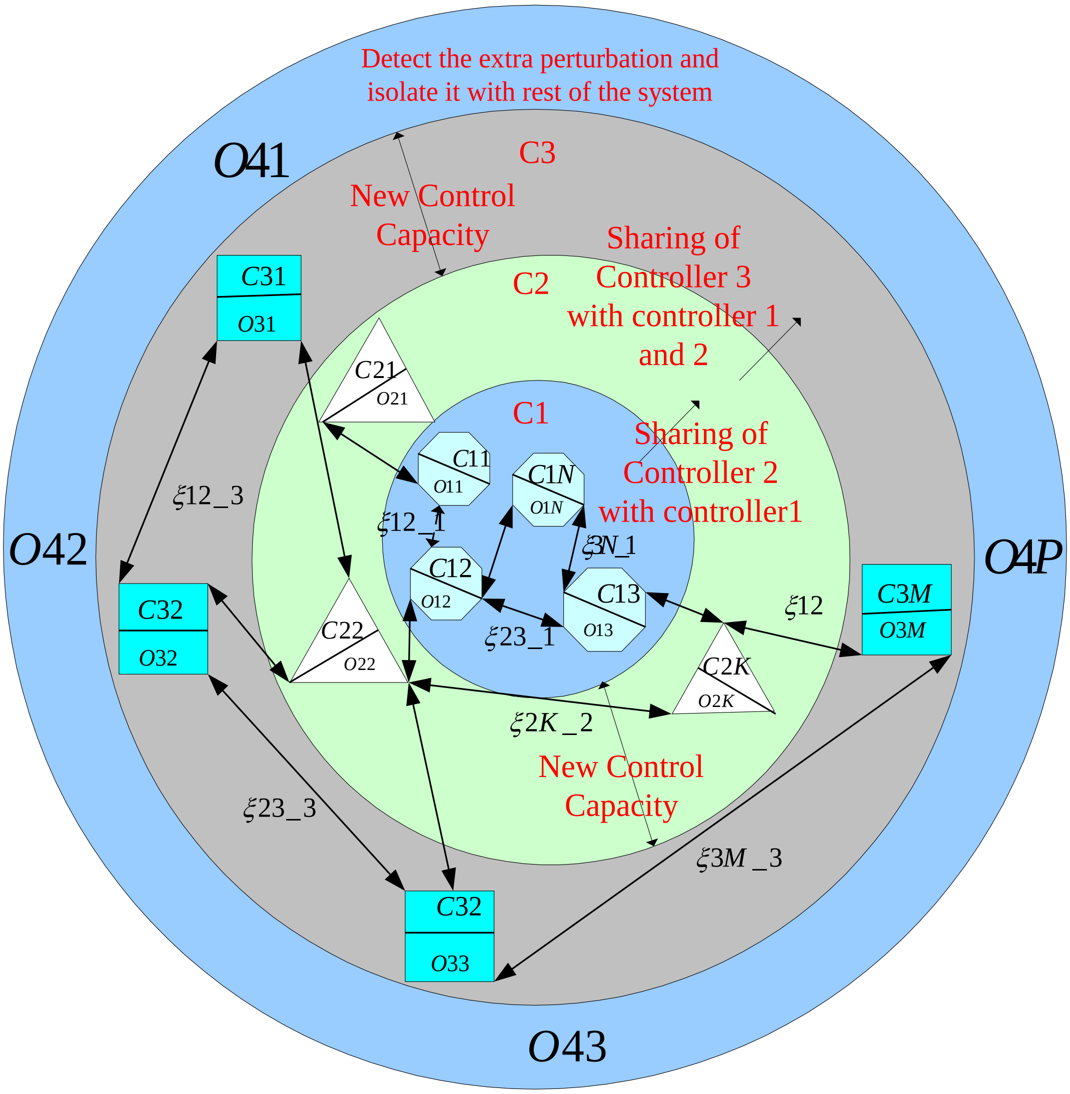

Figure 2.1 Knowledge domain structure

If the system operating condition reaches in the outermost circle (O4P) and all the connected controllers cannot support the control efforts to counteract perturbation, then intelligent power system structure will detect as uncontrollable scenario with existing multi-controller and thus the source of operational shift will be islanded in order to retain the remaining system functionalities. First inner circle represents the control capacity for controller 1 which can be a local controller like PSS. Second inner circle represents controller capacity of both controller 1 and controller 2 (supplementary controller). Similarly, outermost circle represents additional controller module over and above the supplementary one to extend the controller range by augmenting the signal dynamics precisely. Thus controllers 1, 2 and 3 may help system regulation in automation, depending upon the operational shift and mapping criterions adopted for each one and combination as well. It is clarified further that controller 2 and controller 3 are in general FACTS controllers (like UPFC and STATCOM) which quickly respond to ongoing operational shift.

Each controller with specific tuned parameters is capable of handling limited variation in the operating conditions and as those operating condition changes, controller parameters will shift to corresponding new values mapped in the knowledge domain. If current operating point of the system (O1N) is almost at the centre of the circle, then sufficient margin for the deviation is present in the system. However, if O1N is very close to the boundary of the circle or on the circle then system will have least margin and may be ineffective for any further variation. For shifting controller’s parameters from one position to another position, there will be some delay which is called switching delay. The concept includes control parameter’s up-gradation and control shifting/sharing concept. In control parameter’s up-gradation concept, retuning of parameters takes place within the same controller with change in operational shift. In situations of limited capacity of the parameters adjustment, additional standby similar controller architecture may be incorporated apart from the existing one; this is termed as controller shifting to arrive at smooth power flow control. In control sharing, if one control structure is not capable of rejecting perturbation in the system at certain system operating point then another controller act as supplementary controller which is linked with new operational shift by retaining the old one and thus modulates the controller functioning and damps system oscillations. This new control structure with control sharing concept may or may not retain the old dynamics and behavior of the system.

It is preferred first to generate knowledge domain as shown in Figure 2.1 as PSS tuned-1 for operating condition-1,…., PSS tuned-N for operating condition-N. Now the controller has been accordingly mapped which will be driven by intelligent domain mapping depending upon the operating conditions from 1 to N and corresponding PSS tuned parameter will be automatically inducted in controller realization. Now this can be explained as control switching which may be few additional sets of control parameters over and above PSS initial design stage itself / can be supplemented over the period of time by an external circuit which includes the modified operational change based tuning and thus overall PSS parameters are modified/augmented depending on the current changes. The proposed concept demonstrates an intelligent control concept for quick oscillation damping as the operating condition changes. FACTS devices have been used as the supplementary device as PSS approaches to the onset of unacceptable response.

2.4 ESTABLISHING OF INFORMATION MAPPING IN THE KNOWLEDGE DOMAIN

Change in system operating conditions affects the behavior of the system states variables resulting in system oscillations. So retuning of controllers parameters with optimal design from the knowledge domain structure helps to modulate the power flow and stabilize the system quickly. The development of this knowledge domain structure is shown in Figure 2.2. The step procedure for building knowledge domain for all the controllers with their control parameters at dynamic load changing conditions is given in this figure.

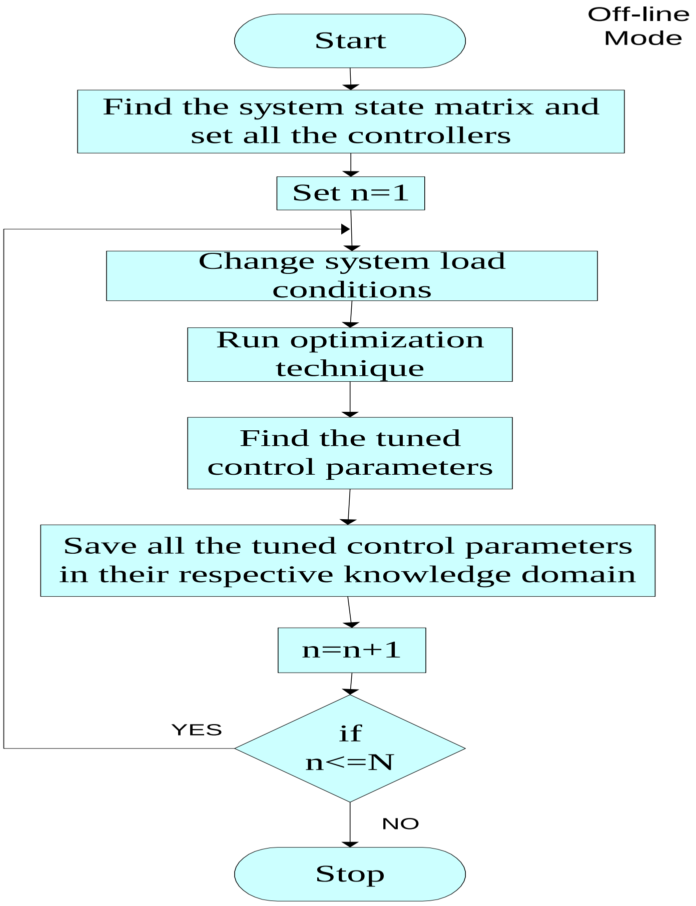

Figure 2.2 Flowchart for offline tuning of controllers with optimization techniques

Each optimization techniques find optimal control parameters (termed as tuned parameters) at different operating conditions and stored in respective knowledge domain which is stamped with operational shift as tag. In this procedure first step is to set the new operating condition and calculate the system state matrix including all the controllers installed in the network. Then find the dynamic response of all the state variables by assigning the control parameters with optimization techniques and find the optimally tuned parameters. Store this tuned parameters stamped with operating conditions in the knowledge domain. Each tuned parameters have the capacity to bear the small change in perturbation. If this perturbation is large and existing control is not capable of absorbing perturbation in the system then controller shifts its position to the new one depending upon the best-suited values and stabilizes the system.

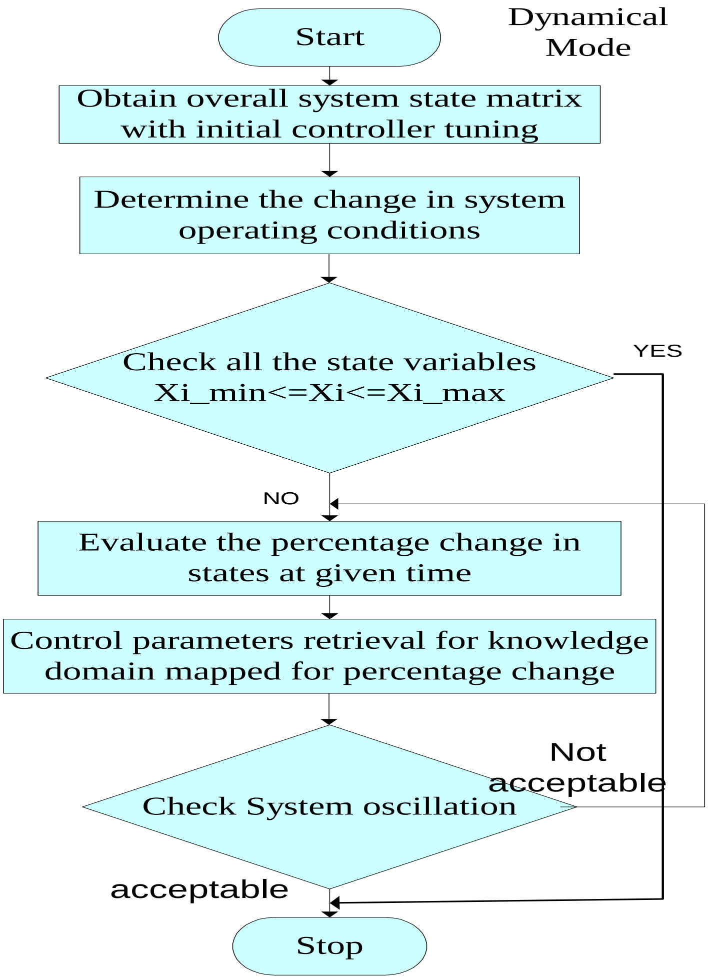

Figure 2.3 Flowchart for controller tuning in dynamical mode

2.5 CONTROLLER PARAMETERS UP-GRADATION BASED ON THE KNOWLEDGE DOMAIN

Figure 2.3 shows the procedure in the dynamical mode for tuning the controller parameters as the system operating condition changes. In dynamical mode, as system operating condition changes, the system state variables response will change and each individual state variable response is then compared with their respective minimum and maximum threshold values (acceptable limits), if signals are within their desired limits, then no change in control parameters is envisaged, otherwise control parameters from their respective knowledge domain are picked up as quickly as possible in order to ensure the satisfactory system performance. Each controller in the system has some capacity to sustain the perturbation occurring in the system and setting of specific controller design can also accommodate small percentage in operational shift. Figure 2.4 represents the general control structure of any power flow controller connected in the system with full capacity of the controller and also the capacity of each tuned parameters at specified operating condition.

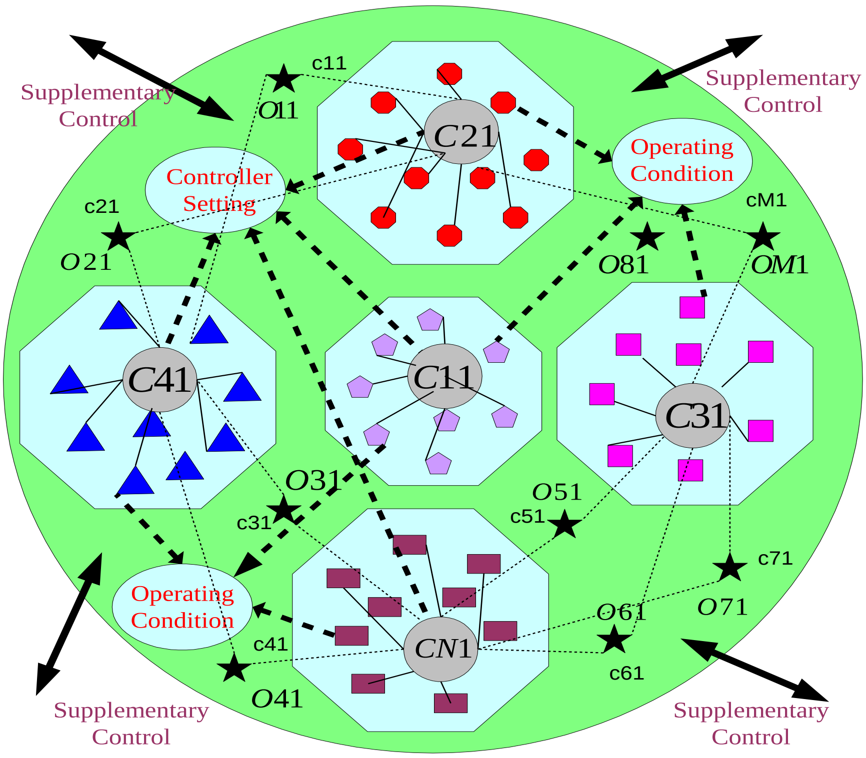

Figure 2.4 Generalized control structure

2.6 INFERENCE FOR INTERFACE KNOWLEDGE DOMAIN

A generalized control structure for one controller has been shown in Figure 2.4, where a complete circle represents full capacity of that controller in terms of absorbing system perturbation. In this circle, there are small circles which represent the capacity of fixed tuned control parameters, and when the system operating condition occurs within their range, corresponding controller setting will stabilize system quickly with improved oscillation damping. In this concept, parameter of controllers are tuned offline for most of the expected system operating conditions (may be based on historical shift observed earlier), then stored in respective knowledge domain as shown in Figure 2.4 but when in online condition some operating condition occurs other than the stored condition (as mentioned by star marks (O11, O21,…OM1)), knowledge domain will be updated with newer shift over and above old one by interpolating the nearest data set and corresponding inference for knowledge domain database is changed. So with new operational shift each time/interval, dynamical knowledge domain is updated and therefore, the control structure so derived with updated parameters base, the controller performance gives the improved results.

This concept also includes the hierarchical control structure modularly with the concept of controller range up-gradation by way of inducting either new set of parameters or new controller in addition to the existing controller for larger domain coverage and thus ensures effective oscillation damping with inference mechanism.

2.7 DEFINING RULE BASE BASED ON INFERENCE MECHANISM

For defining a rule base based on the inference mechanism, there are mainly three aspects for smart power flow controller design, event detection and control injection, dynamic inference linked controller realization and system regulation.

2.7.1 Event Detection and Control Injection

When dynamical change occurs in the system, it will change system state variables response and increase system oscillations. Each individual state variable response is then compared with their respective minimum and maximum threshold values. If all the signals are well within their desired limits and oscillation damping is very fast then no need to change the control parameters otherwise retune the control parameters from their respective knowledge domain as quickly as possible by inference mechanism.

Figure 2.1 shows the knowledge domain concepts for controller tuning with operating conditions change in dynamical mode. First inner circle shows the control capacity for controller 1. For each controller tuned parameters, controllers are capable of handling limited variation/perturbation in the system and as that operating condition change, controller parameters will be retuned to corresponding new values. Figure 2.3 shows the step procedure in the dynamical mode for controllers tuning for flexible operating point tracking. If the perturbation in the system goes beyond the range of controller 1 to faithfully respond then the second controller installed in the network will automatically be inducted as supplementary controller over and above controller 1.

2.7.2 Dynamic Inference Linked Controller Realization

With change in operating conditions, system state variables dynamic responses also change. Knowledge inference mechanism (which links the percentage change in operating condition to the percentage change in system oscillations) retrieves the information about the controller parameters from the respective knowledge domain on the basis of the percentage change in operating condition. Retuning of controller parameters increases the damping in the system oscillations and also improves the stability of the system.

2.7.3 Complete Regulation of the System

System regulation needs to be checked after modulating the power flow in the network. There might be some condition where all the connected controllers will not perform satisfactorily, in that case, isolation of that region from the system will serve as a final control action (may be load shedding or SPS operation) and prevent major collapse in the network.

2.8 CONCLUSION

This chapter presents smart power flow control concept with knowledge domain states mapping for an interconnected multi-area power system. The concept has been used in retuning of controllers as the operational shift occurs. The proposed concept has the flexibility to update the knowledge domain over and above an offline data with newer data set using the nearest data clusters to derive an averaged data within predefined boundary which can be closer to real situation. Also the control so derived, effectively ensures the best damping as compared to other control concept for large network reliability and security. Proposed concept also includes the hierarchical control structure modularly with controller range up-gradation by way of inducting supplementary controller, in addition to the existing controller, for larger operational domain coverage. Such controller architecture results in an effective oscillation damping and quick system regulation.