Structure Based Stabilization and Control Policies for Interonnected Power System(連系電力系統の構造的な安定化と制御方策に関する研究)

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論　文　内　容　要　旨

CHAPTER 1. INTRODUCTION

Cooperation between power utilities in an interconnected system is becoming more and more common. A joint operation in such a system gives immense economical advantages by equalizing load variations, increasing the availability of plant types, keeping the regulating capacity to a desired level etc. Interconnectings however, increase the degree of complexity of power system operating problems mainly arising from the complication of the network topology, dynamic behavior of the disturbance impacts which occur throughout the interconnected system.

Analytical studies and investigation of practical experiences with interconnected systems indicate that generators participate in both local and inter-area oscillations, i.e. a composite mode electromechanical swings. In certain cases of operating conditions and network structure, the damping of these oscillatory modes may be negligible or even negative. The existing approaches are mainly concentrating on local stabilization rather than inter-area one. However, when the composite mode stabilization is considered, i.e. total stabilization of the system, due to the problem dimensionality it is difficult to deal with this problem by means of existing methods.

It is the objective of this research to develop techniques to face with the above problem, where we incorporate the structural properties of power system, such as "coherency" and "time-scale" characteristics to create control strategies for the dynamic stability enhancement of power system through improvement of the damping characteristics of composite oscillatory modes characterized by local and inter-area modes. For this purpose we have developed a new stabilizer so called as Hybrid Power System Stabilizer "HPSS".

CHAPTER 2. DYNAMIC STABILITY ENHANCEMENT OF PWER SYSTEM

Power system stability has been an area of study from the early days of power generation and transmission. As the problem has grown, sophisticated control equipments have been added to the power system to enhance the stability. Increasing emphasis is being placed on automatic controllers to offset the reductions in system stability limits inherent with the introduction of larger units with higher reactances. Contributions have been made to the problem of stability enhancement of power system through modulation of excitation control with various stabilization signals. When considering the total stabilization of interconnected power system, the problem should be studied from the large-scale system view point. However for a realistic size system, the state variables representing different dynamics may be of several hundreds or even thousands which is very difficult and uneconomical for controller design purposes. To overcome this problem in this thesis we have suggested to incorporate some structural properties of power system which are unique characteristics of this large-scale system. These are the coherency and time-scale properties which are very useful for the model aggregation and controller design.

CHAPTER 3. COHERENCY CHARACTERISTICS AND DYNAMIC AGGREGATION OF POWER SYSTEM

Although the reduced order models constructed merely for algebraic or numerical efficiencies may dramatically simplity the computations, but they make the interpretations of the results more difficult, because these reduced models do not have the structure of power system. Therefore a major task in modeling is to achieve simplification which preserves the physical meaning, and this should be based on some physical criterion. An aggregation criterion called coherency has emerged from power system practice. It has been observed that in multimachine dynamics after a disturbance some generators have the tendency to swing together as a group, such coherent machines are clustered into coherent areas which are then represented by equivalent generators. There are several criterions for coherency recognition which are expanded over a wide spectrum of system analysis techniques. The "slow-coherency" is one of the main approaches which is based on the properties of the system eigen-structure, where, the area decomposition is achieved by separation of the slow and fast modes of the system. These areas are aggregable with respect to their center of inertia (C. O. I) variables which represent the slow motion of equivalent machines. Such reduced order models are very useful for the design of control systems suitable for the stabilization of inter-area slow modes.

CHAPER 4. COHERENCY BASED TIME–DICHOTOMY APPROACH TO THE STABILIZATION OF INTERCONNECTED POWER SYSTEM

Motivated by the fact that the existing stabilization techniques are not properly effective on composite mode oscillations of interconnected system, and in order to achieve feasible and simplified control strategies, in this thesis we introduce the concept of time–dichotomy approach to the stabilization of composite oscillatory modes. This approach is mainly based on the slow–coherency and time–scale properties of interconnected system. Time–scale decomposition of the system, where by its fast components associated with rotor dynamics are separated from slower ones is very useful in design of multilevel control systems. The control design is facilitated by the sense that the fast dynamics are modeled with decoupled local subsystem models, and the slow dynamics are treated by aggregated model representing the interaction of subsystems.

We have proposed a two–level control strategy for the total stabilization of interconnected power system. At the first level, local stabilizers are used to damp out the local fast modes, using generator speed as the local input. At the second level of control hierarchy a global stabilizer is used for the improvement of the damping of inter–area mode, where the center of inertia dynamics (C. O. I) of the coherent machines are used as the global input. Parameters of local and global stabilizers are determined for a desired damping of associated modes. The supplementary control signal which will be introduced to the excitation system of some properly selected generators is considered to be as a weighted combination of local and global control signals. Introduction of the weighting parameters in the supplementary control law could give an adaptive feature to the proposed control strategy, through their readjustment with respect to the system situation. The proposed multilevel control structure for a two-area system is shown in Figure 1.

In this chapter feasibility of the proposed method is studied by using classical models of power system and ideal type stabilizers. Simulation studies were carried out and the results confirmed the effectiveness of the proposed stabilization method.

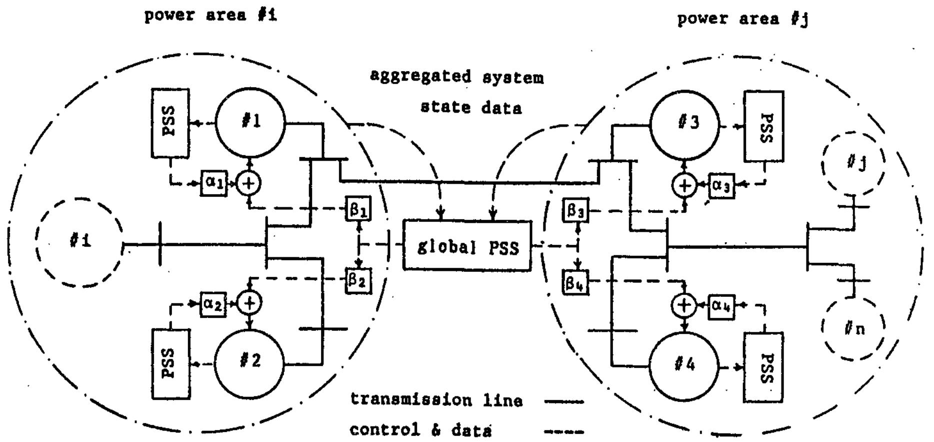

Fig.1: The proposed multilevel control structure applied to a two-area system.

CHAPTER 5. COMPOSITE MODE OSCILLATORY STABILIZATION BY MEANS OF HYBRID POWER SYSTEM STABILIZER

Realization of the proposed idea to be implemented in actual systems is considered in this chapter. Since the power system stabilizer function is imposing additional damping in phase with rotor speed through generator excitation control, and due to the necessity of compensating for phase lags which exists in generator excitation regulation system and field circuit pathes of detailed models of machines, therefore controllers including phase compensator elements should be used for the stability enhancement purposes.

Concerning the above facts we have introduced a new concept of Hybrid Power System Stabilizer "HPSS", Figure 2. This stabilizer is composed of a local PSS and a global PSS both of speed type, and their parameters are designed such that to be effective on both local and inter–area oscillatory modes using detailed models of generators. Here we have developed a reduced order model called "hybrid aggregated model" which will be used for the desing of global control law, Figure 3.

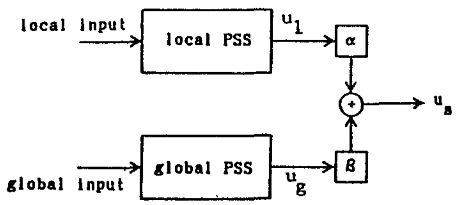

Fig.2: Structure of HPSS.

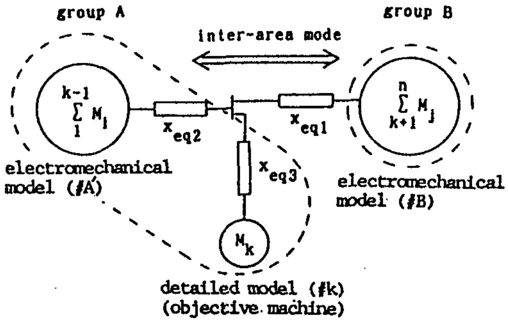

Fig.3: Hybrid aggregated model of two-area system.

Performance of the HPSS has been studied through simulation studied on a test system, Figure 4, for load perturbation disturbances with the results shown in Figures 5 and 6.

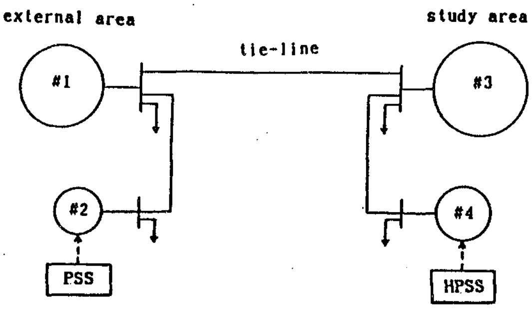

Fig.4: Application of Hybrid PSS.

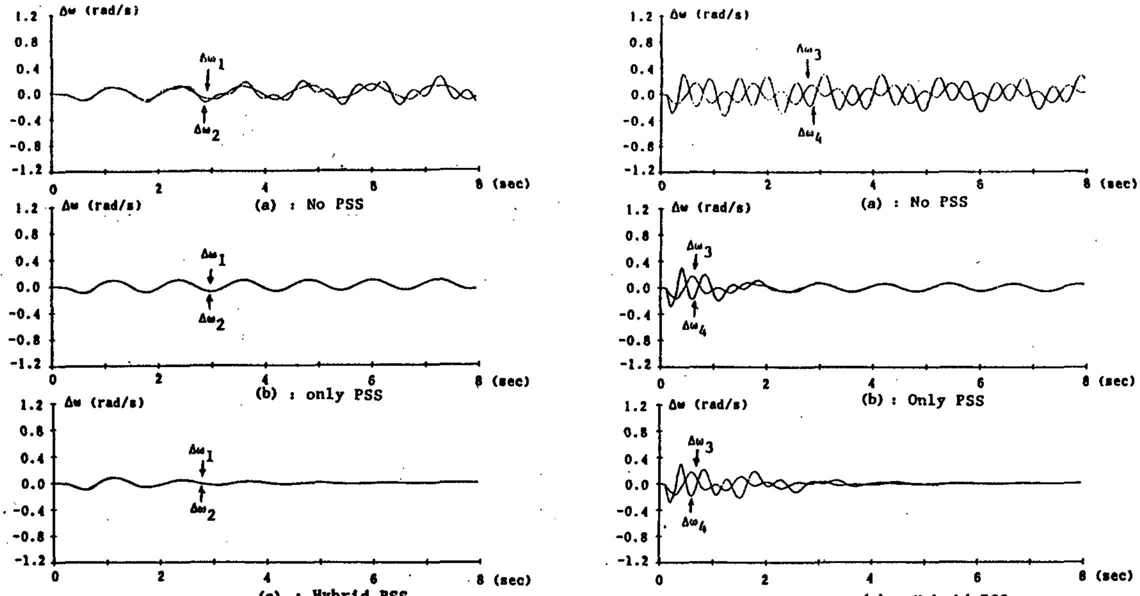

Fig.5: Generator speed deviation for internal fault case study.

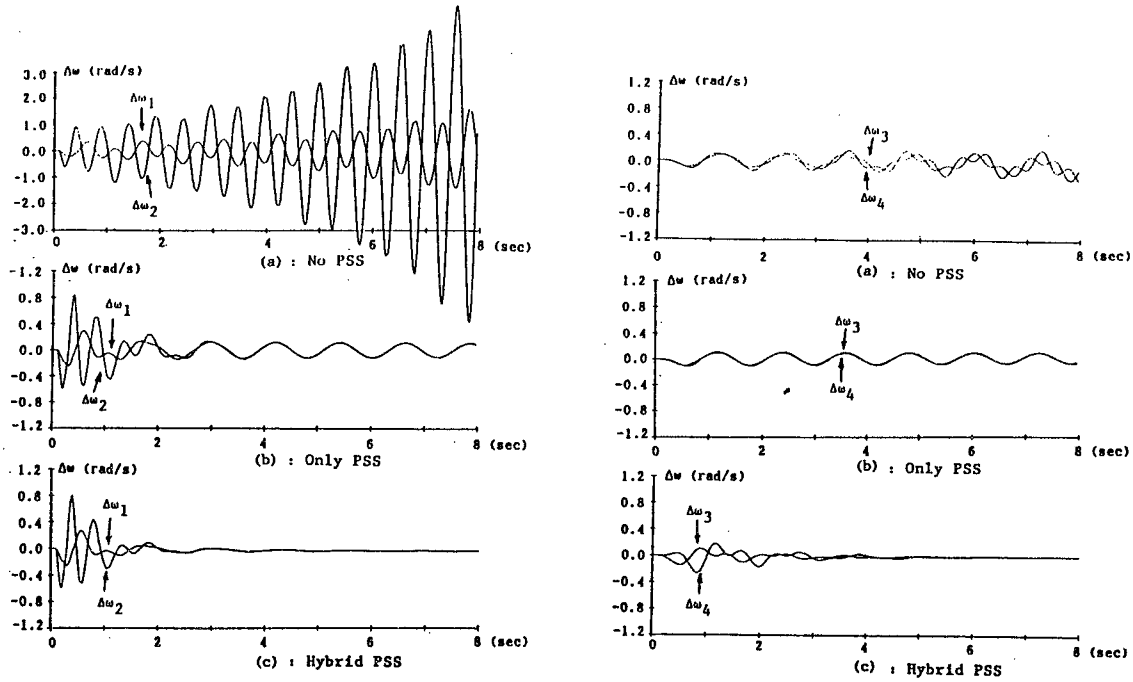

Fig.6: Generator speed deviation for external fault case study.

CHAPTER 6. OPTIMUM ALLOCATION AND PRACTICAL CONSIDERATIONS FOR THE IMPLEMENTATION OF HYBRID PSS

This chapter is mainly dealing with the implementation of Hybrid PSS and several associated subjects including:

(Ⅰ)– stabilizer allocation problem,

(Ⅱ)– estimation of global input,

(Ⅲ)– concept of readjustment of the weighting factors of local and global control signals,

are discussed separately.

Concering the allocation problem, we have introduced an index of "mode–input–assignability" for the determination of those generators which have the most influence on particular mode of study. The proposed method is applicable to both HPSS and also to the existing PSS.

Regarding the second problem, due to the economical and technical reasons, it is considered that for the input of the global PSS, instead of C.O.I data an approximated value obtained from a suitable combination of the rotor speed data of a few properly selected "key generators" be used in practice. An algorithm for the selection of these key generators is proposed and a least square based estimation method is used for the determination of optimum combination parameters.

Finally, the possibility of changing the weighting parameters of local and global control signals is discussed. This concept provides a more flexible functioning for 'the HPSS with respect to the system oscillatory situations following a fault, which depends to the nature of disturbance. Suggestions and associated discussions on the above subject is available on the last part of this chapter.

CHAPTER 7. CONCLUSIONS

This research was aimed to develop new control techniques to meet problems concerning with dynamic stability enhancement of interconnected power system. It was shown that incorporating of structural properties of the system is very useful in developing feasible control strategies for such large-scale systems.

審 査 結 果 の 要 旨

電力系統は，発電機群と流通ネットワークの組み合せにより複雑な多モードの電気機械振動系を構成しており，時々刻々の負荷変化などのじょう乱により，系統には複合モードの電力動揺が発生することになる。従って，高品質の電力を供給するためには，これら持続性動揺を抑制することが必要となり，従来から発電機の励磁機に安定化信号を加えるＰＳＳ法，発電機の加速を抑制する制動抵抗挿入法などが実用化されている。しかしこれらの方策のいずれも，個別系統に生起する局所的モードの抑制を目標としており，連系系統にまたがる全域的モードを対象としていない。本論文は連系電力系統に構造的に生起する複合モードの安定化と制御方策に関する研究成果をまとめたものであり，全編７章よりなる。

第１章は序論である。

第2章では，本研究で開発したハイブリッドＰＳＳ（ＨＰＳＳ）設計の基礎となる励磁機制御方式の研究状況，関連する系統機器のモデル化について述べている。

第３章では，連系電力系統に生起する複合モードと凝集性（コヒーレンシィ）の関係について検討している。系統間の連系線容量が各個別系統容量に比べて小さいため，連系系統の動揺モードは，全域的モードと局所的モードに類別されることを示し，本研究に適用する系統縮約方法について考察している。

第４章では，ＰＳＳ方式を利用した複合モード抑制の可能性について基礎的な検討を行っている。発電機，ＰＳＳともに単純なモデルを用い，連系系統の凝集性を利用して，局所的モードの抑制方策と，全域的モードの安定化方策を分離して設計している。これらをそれぞれに重みずけし加え合せて複合モードの抑制信号とするＰＳＳ方式を開発している。これは次章のＨＰＳＳの基礎となる手法を示唆したものであり，重要な成果である。

第５章では，複合モードを抑制するＨＰＳＳを検討している。発電機は実用的高次モデルを用い，ＰＳＳも補償特性を考慮した精密モデルを使用している。全域的モード抑制方策の設計にあたっては，発電機のグループ化を工夫し，発電機モデルの精密度を維持して設計する方法を開発している。これは有用な実用的手法である。

第６章では，ＨＰＳＳが最も効果のある配置場所の選定方法と，ＨＰＳＳの動作に必要な広域的データの生成方法について，実用化の見地から検討を行っている。

第７章は結論である。

以上要するに本論文は，連系電力系統に構造的に生起する複合モードを安定化する方策としてハイブリッドＰＳＳを開発し，その有効性を確認したものであり，電力工学に資する所が少なくない。

よって，本論文は工学博士の学位論文として合格と認める。