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Decentralised power system load frequency control beyond the limit of diagonal dominance

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Abstract

The design of decentralised robust load frequency control for interconnected multi-area power systems is studied in this paper. It is shown that although the design can be naturally formulated as a large-scale system decentralised control problem, it can be translated into an equivalent problem of decentralised controller design for a multi-input multi-output (MIMO) control system. It is known that simple controllers can be designed to achieve satisfactory performances if diagonal dominance can be achieved in a multivariable system. This is further extended in this paper. Using the design method proposed in this paper, even when the diagonal dominance cannot be achieved, subject to a condition based on the structured singular values (SSVs), each local area load-frequency controller can be designed independently. The robust stability condition for the overall system can be easily stated as to achieve a sufficient interaction margin, and a sufficient gain and phase margin during each independent design. © 2001 Elsevier Science Ltd. All rights reserved.

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1. Introduction

In the dynamical operation of power systems, it is usually important to aim for decentralisation of control action to individual areas. This aim should coincide with the requirements for stability and load-frequency scheduling within the overall system. In a completely decentralised control scheme, the feedback controls in each area are computed on the basis of measurements taken in that area only. This implies that no interchange of information among areas is necessary for the purpose of load-frequency control (LFC). The advantages of this operating philosophy are apparent in providing cost savings in data communications and in reducing the scope of the monitoring network.

In the LFC function, it is necessary that the system frequency and the inter-area tie-line power are kept as near to the scheduled values as possible through control action. The important requirement for system stability may be conveniently met by adopting a global policy for design, for example based on well-established principles of pole-placement or optimal control by state-feedback. Such an approach is to be used with decentralised control, the state-vector for the entire system should be made available for the generation of local feedback control signals in all areas. This requirement may be met if a reconstruction of the whole system state-vector is made within each area only, i.e. if the system state-vector is observable from area measurements. However, even if the observability condition is satisfied, the resulted controllers with appropriately designed observers are normally quite complicated and this approach is not suitable for a large power system where the total number of the state variables is large.

Another important issue in the load-frequency controller design is robustness. An industrial plant such as a power system always contains some uncertainties. Several authors [1–4] applied the concept of variable-structure systems (VSS) to the design of load-frequency controllers. Various adaptive control techniques [5–7] and the 'Riccati equation approach' [8] were also suggested for the LFC design. The all above proposed methods with consideration of the robustness are based on the state-space approach. It is known that [9], although many power system controller designs can be naturally formulated as a large-scale system decentralised

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control problem, it can be translated into an equivalent problem of decentralised controller design for a multi-input multi-output (MIMO) control system. The frequency-response based robust controller design methods, for example H_∞ or μ synthesis [10], may be applied to such a MIMO system. However, applying these methods in general leads to a centralised controller.

One of the most important progress in control theory and application was the direct and inverse Nyquist array methods developed by Rosenbrock and his colleagues [11–13]. The design is based on achieving the required diagonal dominance, so that each control loop can be designed independently. However, it has long been recognised that the main difficulty in applying the Nyquist array method is to obtain the required diagonal dominance (row dominance or column dominance). In particular, if the controller is restricted to be diagonal, the possibility of achieving diagonal dominance depends on whether the P–F (Perron–Frobenius) eigenvalues of all the matrices derived from the frequency response magnitudes are less than 2 [12,14]. As shown in Sections 2 and 3, for the two sample systems studied in this paper, the above P–F eigenvalue condition is not satisfied.

To break the limit imposed by the diagonal dominance, the structured singular value (SSV) μ is applied in this paper in a different way from those commonly used in the robust control literature [10]. It is shown that subject to a condition based on μ, each local area controller can be designed independently. The robust stability condition for power systems with local area controllers can be stated as to achieve a sufficient interaction margin, and sufficient gain and phase margins during each independent design. It is shown in this paper that, within this framework, simple local area controllers can be designed to achieve good system performances.

For ease of presentation, the proposed design method is illustrated in Section 2 by a design for a sample two-area power system, which is widely used by the researchers in this area [1,4,15]. The same design for a more realistic multi-area (four area) power system is presented in Section 3. Some conclusions are made in Section 4.

2. Decentralised controller design based on SSVs

2.1. A sample two-area system

Fig. 1 is a block diagram for the LFC of a two-area power system. The nomenclature used and the nominal parameter values, in per unit (pu), are given in Appendix A.

A state-space model for the system of Fig. 1 can be constructed as

$$\dot{\mathbf{x}} = \mathbf{A}\mathbf{x} + \mathbf{B}\mathbf{u} \tag{1}$$

$$\mathbf{y} = \mathbf{C}\mathbf{x}$$

where $\mathbf{u} = [u_1\ u_2]^{\mathrm{T}}$; $\mathbf{y} = [y_1\ y_2]^{\mathrm{T}} = [\Delta f_1\ \Delta f_2]^T$

$$x = [\Delta f_1 \Delta P_{T1} \Delta P_{G1} \Delta P_{c1} \Delta P_{\mathrm{tie}} \Delta f_2 \Delta P_{T2} \Delta P_{G2} \Delta P_{c2}]^{\mathrm{T}}$$

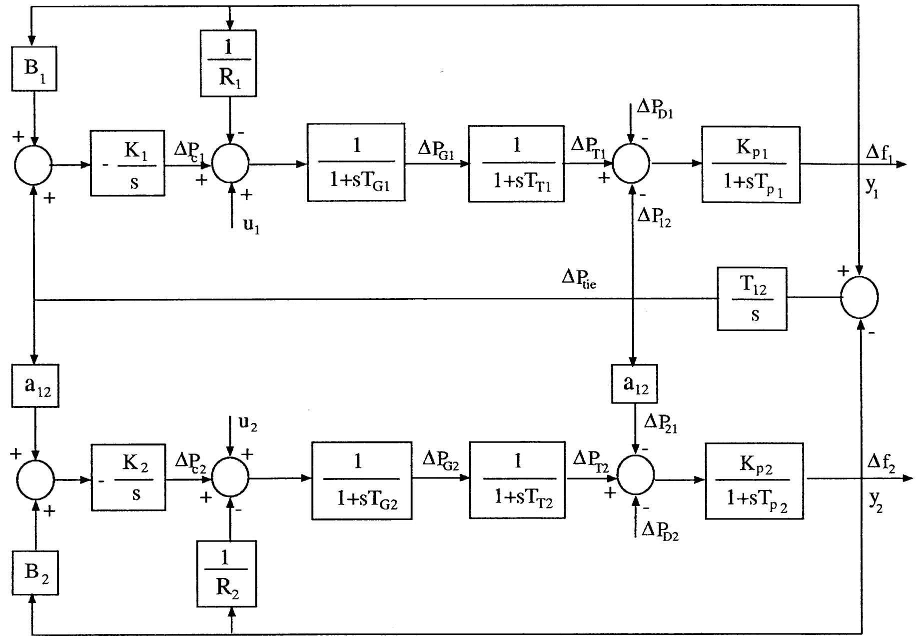

Fig. 1. Block diagram of a two-area power system.