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Decentralized load frequency control in an interconnected power system using Coefficient Diagram Method

Michael Z. Bernard [b], Tarek Hassan Mohamed [a,*], Yaser Soliman Qudaih [b], Y. Mitani [b]

[a] Faculty of Energy Engineering, Aswan University, Egypt
[b] The Department of Electrical Engineering and Electronics, Kyushu Institute of Technology, Japan

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ABSTRACT

This paper presents a new load frequency control (LFC) design, using the Coefficient Diagram Method (CDM) in a multi-area power system. The CDM controller has been designed to reduce the effect of uncertainties owing to variations in the parameters of governors and turbines as well as load disturbance. Each local area controller is designed independently, such that, stability of the overall closed-loop system is guaranteed. The CDM structure is built on the frequency response model of multi-area power system, and physical constraints of the governors and turbines are considered. Digital simulations for both two and three-area power systems are provided to validate the effectiveness of the proposed scheme. From the simulation results it is shown that, considering the overall closed-loop system performance with the proposed CDM technique, robustness is demonstrated in the face of uncertainties due to governors and turbines parameters variation and loads disturbances. A performance comparison between the proposed controller, model predictive controllers (MPC), and a classical integral control (I) scheme is carried out, confirming the superiority of the proposed CDM technique.

Introduction

When power systems generate and distribute electrical power to factories and households, to meet varieties of power needs, both the active and reactive power balances must be maintained between generation and utilization of the electric power. Those two balances correspond to two equilibrium points, namely: frequency and voltage. When either voltage or frequency is reset at a new level due to some disturbance or instability problems, the equilibrium points will float. A quality electric power system requires the frequency and voltage to remain at standard values during operation.

Thus, a control system is important to cancel or reduce the effects of the random load changes, and to keep the frequency and voltage at the standard values. Although active power and reactive power affect the frequency and voltage respectively, the frequency is highly dependent on the active power while the voltage is highly dependent on the reactive power. Hence, the control issues in power systems can be decoupled into two independent problems. One is about the active power and frequency control while the other is about the reactive power and voltage control. The active power and frequency control is referred to as load frequency control (LFC) [1] which is the major concerned of this paper. The main goal of the load frequency control (LFC) of a power system is to maintain the frequency of each area, and tie-line power flow (in an interconnected power system) within specified tolerance. This is accomplished by adjusting the mega-watt (MW) outputs of the generators so as to accommodate fluctuating load demand.

Today, control system designers are trying to apply different control algorithms in order to find the best controller parameters to obtain optimum solutions. Fixed parameter controllers, such as an integral controller or a proportional integral (PI) controller, is also widely employed in the LFC application.

Fixed parameter controllers are designed at nominal operating points, and may no longer be suitable in all operating conditions. For this reason, adaptive gain scheduling approaches have been proposed for LFC synthesis [3]. This method overcomes the disadvantages of the conventional Proportional Integral and Derivative (PID) controllers which need adaptation of controller parameters. However, it faces some difficulties like the instability of transient response as a result of abrupt changes in the system parameters, in addition to the impossibility of obtaining accurate linear time invariant models at variable operating points [3]. In addition to dealing with changes in system parameters, fuzzy logic controllers

* Corresponding author. Tel.: +20 1125911572.
E-mail addresses: physicsboy2electrical@aol.com (M.Z. Bernard), tarekhie@yahoo.com (T.H. Mohamed), yaser_qudaih@yahoo.com (Y.S. Qudaih), mitani@ele.kyutech.ac.jp (Y. Mitani).

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have been used in many reports for LFC design in a two area power system [4,5]. The applications of artificial neural network and genetic algorithms in LFC have been reported in Refs. [6,7]. In spite of these efforts, it seems that, although estimation of parameters is not required, the parameters of the controllers can be changed generally very quickly; but despite the promising results achieved, the control algorithms are complicated and unstable transient response could still be observed. Therefore, some other elegant techniques are needed to achieve a more desirable performance.

Recently, some papers have reported the application of model predictive control (MPC) technique on load frequency control issue [8,9]. In Ref. [8], the use of MPC in a multi area power system is discussed. In Ref. [9], the effect of merging wind turbines on the multi area power system controlled by MPC is discussed. From [8] and [9], fast response and robustness against parameter uncertainties and load changes can be obtained using MPC controller. On the other hand, positive effect of wind turbines (WTs) was observed, but, the problem of calculations remains an obstacle in the way of real time implementation of MPC.

In fact, due to increase in the complexity and change of the power system structure, other techniques are needed to achieve a desirable performance.

In this work, a decentralized robust load frequency control (LFC) strategy involving Coefficient Diagram Method (CDM) is developed. This strategy is an algebraic approach applied to a polynomial loop in the parameter space, where a special diagram called coefficient diagram is used as the vehicle to carry the necessary design information, and as the criteria of good design [10].

The CDM is fairly new for load frequency control application. However, its basic principle has been known in industries and control community for more than 40 years with successful application in servo control, steel mill drive control, gas turbine control, and spacecraft attitude control [11].

In this paper, decentralized load frequency control for a multi-area power system has been developed based on the CDM technique. The parameters of the polynomials of CDM technique have been designed based on the dynamic model of the multi-area power system. The effects of the physical constraints such as generation rate constraint (GRC) and speed governor dead band [2] are considered. The power system with the proposed CDM technique has been tested through the effect of uncertainties due to governor and turbine parameters variation, and load disturbance using computer simulation. A comparison has been made between the CDM and the traditional integral controller confirming the superiority of the proposed CDM technique. The simulation results proved that the proposed controller can be applied successfully to the application of power system load frequency control. With the aim of robustness evaluation of the proposed CDM, another comparison between the proposed method and MPC technique has been made in a three area power system in case of both load changes and parameters uncertainties. The simulation results supported that CDM acts as robust control and more suitable for real time implementation.

The rest of the paper is organized as follows: the description of the dynamics of the interconnected power system is given in Section 'System dynamics'. A general consideration about CDM and its design are presented in Section 'Coefficient Diagram Method'. The implementation scheme of a two area power system together with the CDM technique is described in Section 'Case study'. Simulation results and general remarks are presented in Section 'Results and discussions'. Finally, the conclusion is given in Section 'Conclusion'.

System dynamics

A multi-area power system comprises areas that are interconnected by tie-lines. The trend of frequency measured in each control area is an indicator of the trend of the mismatch power in the interconnection, and not in the control area alone. The LFC system in each control area of an interconnected (multi-area) power system should control the interchange power with the other control areas as well as its local frequency. Therefore, the dynamic LFC system model must take into account the tie-line power signal. For this purpose, consider Fig. 1 which shows a power system with *N*-control areas [2].

In this section, a frequency response model for any area-*i* of *N* power system control areas with an aggregated generator unit in each area is described [2].

The overall generator-load dynamic relationship between the incremental mismatch power ($\Delta P_{mi} - \Delta P_{Li}$) and the frequency deviation (Δf_i) can be express as:

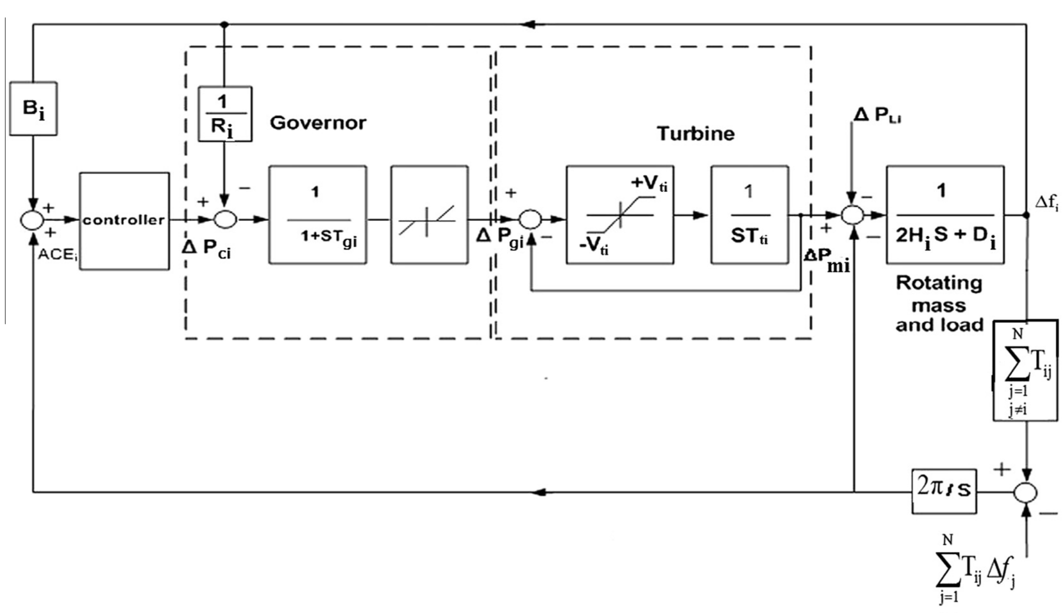

Fig. 1. Dynamic model of a control area in an interconnected environment.