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Distributed load frequency control in an interconnected power system using ecological technique and coefficient diagram method

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ABSTRACT

This paper presents a load frequency control (LFC) design, using both of coefficient diagram method (CDM) and ecological optimal technique (ECO) in a multi-area power system. The proposed 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. Also, the standard Kalman filter technique has been employed to estimate the full states of the system including the area frequency deviation, these states has been employed by the (ECO) state feedback optimal controller to produce the optimal control signal. Digital simulations for 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 + ECO technique, robustness is demonstrated in the face of uncertainties due to governors, turbines parameters variation and loads disturbances. A performance comparison between the proposed controller, CDM alone, and a classical integral controller (I) scheme is carried out, confirming the superiority of the proposed CDM + ECO technique.

Introduction

Load frequency control LFC becomes an important function of power system operation where the main objective is to regulate the output power of each generator at prescribed levels while keeping the frequency fluctuations within pre-specified limits [1,2].

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. In addition to dealing with changes in system parameters, fuzzy logic controllers 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 [6,7]. In spite of these efforts, the control algorithms are complicated and unstable transient response could still be observed. Therefore, some other 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 [8], the use of MPC in a multi area power system is discussed. From [8,9], fast response and robustness against parameter uncertainties and load changes can be obtained using MPC controller.

In [10], 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 information, and as the criteria of good design. The simulation results proved that the CDM controller can be applied successfully to the application of power system load frequency control.

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

On the other hand, the idea of using Ecological Sign Stability approach for designing robust controllers for engineering systems has attracted attention with promising results [11]. In ecological technique, the robustness measures for parameter perturbation are considerably improved if the 'nominal' system is taken (or driven) to be a 'sign stable' system. The fields of population biology and ecology deal with the analysis of growth and decline of populations in nature and the struggle of species to predominate over one another. Many mathematical population models were proposed over the last few decades [12–17].

In this paper, decentralized load frequency control for a multi-area power system has been developed based on both of the CDM technique and Ecological optimal control method. The parameters of the polynomials of CDM technique have been designed based on the dynamic model of the multi-area power system. In addition, ECO designed to produce an optimal feedback control signal. Kalman filter has been employed to estimate the full states of the system. The optimal state feedback gains and the Kalman state space model have been calculated off-line in order to reduce the computational burden. 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 + ECO 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 proposed method, CDM alone and the traditional integral controller confirming the superiority of the proposed CDM + ECO technique.

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". ECO with Kalman filter is presented in Section "Ecological technique". A general consideration about CDM and its design are presented in Section "Coefficient diagram method". The implementation scheme of a three area power system together with the CDM + ECO 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 "Conclusions".

System dynamics

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.

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. 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.

Considering that:

ΔP_{gi}	The governor output change of area i
ΔP_{mi}	The mechanical power change of area i
Δf_i	The frequency deviation of area i
ΔP_{Li}	The load change of area i
ΔP_{ci}	supplementary control action of area i
y_i	The system output of area i
H_i	Equivalent inertia constant of area i
D_i	Equivalent damping coefficient of area i
R_i	Speed droop characteristic of area i
T_{gi}, T_{ti}	Governor and turbine time constants of area i
ACE_i	The control error of area i
B_i	A frequency bias factor of area i
T_{ij}	Tie-line synchronizing coefficient with area j
$\Delta P_{tie,i}$	The total tie-line power change between area i and the other areas
Δv_i	Control area interface, $v_i = \left[\sum_{j=1, j\neq i}^{N} T_{ij}\Delta f_j\right]$

A generator unit in power systems converts the mechanical power received from the turbine into electrical power. But for LFC, we focus on the rotor speed output (frequency of the power systems) of the generator instead of the energy transformation. Since electrical power is hard to store in large amounts, the balance has to be maintained between the generated power and the load demand.

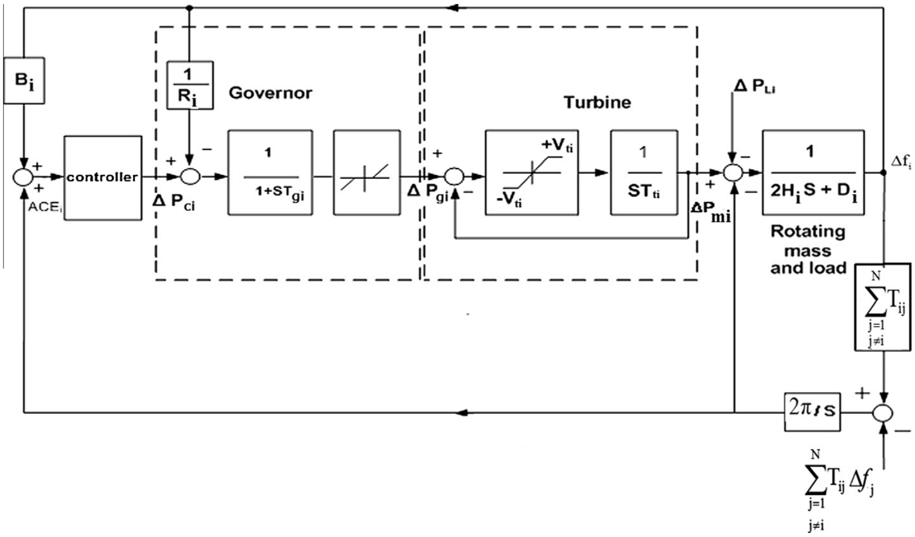

Fig. 1. Dynamic model of a control area in an interconnected environment [2].