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Neural predictive controller of a two-area load frequency control for interconnected power system

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Abstract The present paper investigates the load-frequency control (LFC) for improving power system dynamic performance over a wide range of operating conditions. This study proposed design and application of the neural network model predictive controller (NN-MPC) on two-area load frequency power systems. Neural network model predictive control (NN-MPC) combines reliable prediction of neural network with excellent performance of model predictive control using nonlinear Levenberg–Marquardt optimization. The controller used the local power area error deviation as a feedback signal. To validate the effectiveness of the proposed controller, two-area power system is simulated over a wide range of operating conditions and system parameters change. Further, the performance of the proposed controller is compared with a fuzzy logic controller (FLC) through simulation studies. Obtained results demonstrate the effectiveness and superiority of the proposed approach.

1. Introduction

Large-scale power systems are normally composed of interconnected subsystems. The connection between the control areas is done using tie lines. Each area has its own generator or multigenerators and it is responsible for its own load and scheduled interchanges with neighboring areas. Because of a given power system loading is never constant and to ensure the quality of power supply, a load frequency controller is needed to maintain the system frequency at the desired nominal value. It is known that changes in real power affect mainly the system frequency and the input mechanical power to generators is used to control the frequency of the output electrical power. In a deregulated power system, each control area contains different kinds of uncertainties and various disturbances due to increased complexity, system modeling errors and changing power system structure. A well designed and operated power system should cope with changes in the load and with system disturbances and it should provide acceptable high level of power quality while maintaining both voltage and frequency within tolerable limits [1–3].

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During the last decades, various control strategies for LFC have been proposed [1–10]. This extensive research is due to the fact that LFC constitutes an important function on 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-defined limits. Robust adaptive control schemes have been developed [4–7] to deal with changes in system parametric under LFC strategies. A different algorithm has been presented in [8] to improve the performance of multi-area power systems. Viewing a multi-area power system under LFC as a decentralized control design for a multi-input multi-output system, it has been shown in [9] that a group of local controllers with tuning parameters can guarantee the overall system stability and performance. The result reported in [1,2] demonstrates clearly the importance of robustness and stability issues in LFC design. In addition, several practical points have been addressed in [5,10] which include recent technology used by vertically integrated utilities, augmentation of filtered area control error with LFC schemes and hybrid LFC that encompasses an independent system operator and bilateral LFC.

The applications of artificial neural networks, genetic algorithms, fuzzy logic and optimal control to LFC have been reported in [3–10].

Predictive control is now widely used in industry and a large number of implementation algorithms. Most of the control algorithms use an explicit process model to predict the future behavior of a plant and because of this, the term model predictive control (MPC) is often utilized [11–13]. The most important advantage of the MPC technology comes from the process model itself, which allows the controller to deal with an exact replica of the real process dynamics, implying a much better control quality. The inclusion of the constraints is the feature that most clearly distinguishes MPC from other process control techniques, leading to a tighter control and a more reliable controller. Another important characteristic, which contributes to the success of the MPC technology, is that the MPC algorithms consider plant behavior over a future horizon in time. Thus, the effects of both feedforward and feedback disturbances can be anticipated and eliminated, which permits the controller to drive the process output more closely to the reference trajectory.

Several versions of MPC techniques are Model Algorithmic Control (MAC) [14], Dynamic Matrix Control (DMC) [15], and Internal Model Control (IMC) [16]. Although the above techniques differ from each other in some details, they are fundamentally the same, because all of them are based on linear process modelling.

The neural network model predictive control (NN-MPC) is another typical and straightforward application of neural networks to nonlinear control. When a neural network is combined with MPC approach, it is used as a forward process model for the prediction of process output [17,18]. Neural model predictive control has been applied on process control as chemical [19] and industry [18] applications. But, applying MPC on power system stability and control is still very slightly [20].

The main objective of this study is to investigate the application of neural model predictive controller on the load frequency control and inter area tie-power control problem for a multi-area power system. The system is modeled and the NN-MPC is designed and applied on the system. A comparison between the proposed NN-MPC and a FLC is presented at different conditions and evaluated. The feasibility and effectiveness of the LFC together with the proposed neural model predictive controller have been demonstrated through computer simulations. Simulation results have proved that the proposed controller can give better overall performance. Simulation results show also that the NN-MPC gives promising results.

2. Two-area load-frequency control model

Fig. 1 shows a block diagram of the ith area of an n-area power system. Because of small changes in the load are expected during normal operation, a linearized area model can be used for the load-frequency control. The following one area equivalent model for the system is adopted.

The system investigated comprises an interconnection of two areas load frequency control. The block diagram of two areas load frequency control model is shown in Fig. 2. The model equations of two areas load frequency control can be written as follows [21]:

$$\Delta\dot{P}_{G1} = \frac{-1}{T_{G1}}\Delta P_{G1} + \frac{-1}{R_1 T_{G1}}\Delta f_1 + \frac{1}{T_{G1}}u_1 \tag{1}$$

$$\Delta\dot{P}_{T1} = \frac{1}{T_{T1}}\Delta P_{G1} + \frac{-1}{T_{T1}}\Delta P_{T1} \tag{2}$$

$$\Delta\dot{f}_1 = \frac{K_{p1}}{T_{p1}}\Delta P_{T1} + \frac{-1}{T_{p1}}\Delta f_1 - \frac{K_{p1}}{T_{p1}}\Delta P_{tie} - \frac{K_{p1}}{T_{p1}}\Delta P_{d1} \tag{3}$$

$$\Delta\dot{P}_{tie} = T_{12}\Delta f_1 - T_{12}\Delta f_2 \tag{4}$$

$$\Delta\dot{P}_{G2} = \frac{-1}{T_{G2}}\Delta P_{G2} + \frac{-1}{R_2 T_{G2}}\Delta f_2 + \frac{1}{T_{G2}}u_2 \tag{5}$$

$$\Delta\dot{P}_{T2} = \frac{1}{T_{T2}}\Delta P_{G2} + \frac{-1}{T_{T2}}\Delta P_{T2} \tag{6}$$

$$\Delta\dot{f}_2 = \frac{K_{p2}}{T_{p2}}\Delta P_{T2} - \frac{1}{T_{p2}}\Delta f_2 - \frac{a_{12}K_{p2}}{T_{p2}}\Delta P_{tie} - \frac{K_{p2}}{T_{p2}}\Delta P_{d2} \tag{7}$$

where

Δf_i = the incremental frequency deviation for the ith area;
ΔP_{di} = the incremental change in load demand for the ith area;
ΔP_{tie} = the incremental change in tie-line power;
ΔP_{Gi} = the incremental change in governor position for the ith area;
ΔP_{Ti} = the incremental change in power generation level for the ith area;
B_i = the bias constant for the ith area;
T_{Gi} = the governor time constant for the ith area;
T_{Ti} = the turbine time constant for the ith area;
K_{pi} = power system gain for the ith area;
T_{pi} = power system time constant for the ith area;
T_{ij} = the synchronizing constant between the ith and jth area;
R_i = gain of speed droop feedback loop for the ith area;
ACE_i = area control error of the ith area;
u_i = control input of the ith area.

The two areas power system can be written in state-space form as follows:

$$\dot{x} = Ax + Bu + \delta d \tag{8}$$