

Sliding Mode Controller-based Load Frequency Regulation for a Two-area Interrelated Power System

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Abstract

This study presents the use of the sliding mode control approach for power systems load frequency regulation. A sliding mode load frequency controller is part of a two-area power system. Both reheat and non-reheat. These two regions each have a distribution of thermal turbines. Nonlinearities such as governor dead region and production rate limitations are included in the block diagram of a power plant model. Our control objective is to manage the power system's load frequency inaccuracy when various load variations and parameter variations occur. The sliding mode controller (SMC) is modelled using a two-area integrated power system with nonlinearities. The sliding mode controller's robustness is demonstrated by these simulation findings. Furthermore, it demonstrates how tie line power errors and frequency mistakes converge to zero. Sliding mode controller performance is contrasted with fuzzy, PID, and traditional PI controllers. These comparisons demonstrate that SMC outperforms the other controllers in terms of effectiveness and insensitivity to parameter changes.

Keywords: Load frequency control, sliding mode controller, Governor dead band, generation rate constant.

INTRODUCTION

These days, contemporary electric power networks are made up of many power zones connected to one another by tie lines. The standard of quantification for the velocity at which two electricity zones can link is called frequency. The frequency deviates from its intended value if the generation does not keep up with variations in load. Frequency deviation and tie line power fluctuations are caused by load variations and generation deficiencies because the power system is made up of interconnected control regions connected by tie lines [1]. When a frequency deviates from its standard value of 50 Hz, it results in high magnetic current in synchronous machines or induction motors, which harms the machinery.

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Excessive frequency variation can also lead to transmission line overload, tamper with system protective mechanisms, and eventually cause the power system to fail [2]. The electricity system is equipped with a load frequency control (LFC) to address the issue of frequency variation. LFC specifically has two goals. One is to keep power systems operating at 60 Hz with a 0.5 Hz tolerance. Maintaining an interconnected power system's scheduled power interchange is the other goal.

These days, load frequency management is handled by PI type controllers with constant

parameters in most control regions [3–6]. Nevertheless, the transient responses of frequency in systems with PI control exhibit longer settling times and larger overshoots. Systems using PI control, however, require more time to settle and exhibit comparatively large overshoots in their transient reactions to frequency. Additionally, the PI control algorithm only allows the system to behave as needed within a specific range of the nominal operating point, for which it was intended. However, a power system's operational point typically varies over time, making power plant features undesirable. Prospective electrical systems will integrate large volumes of distributed generation with a high percentage of renewable energy sources, which will increase system unpredictability and require new requirements for that power system's load frequency control [7].

Every degree of frequency control must also be anticipated in the short term.

Advanced controllers, which retain the following specifications, should be designed in place of PI controllers to lessen disruption.

- Preserving the control quality across a broad range of conditions
- Reduce the transient reactions of the frequency to prevent overshoots.
- Robust against system uncertainties and insensitive to changes in parameters and to offer superior disturbance rejection.

Related Studies

Numerous control methods are offered to address the shortcomings of the Pi controller. Kumar et al. suggested a sliding mode controller construction technique for controlling frequencies in a connected power system. Four-parameter sliding interface has been used for the load frequency control (LFC) systems concept [1]. The SMC approach was first introduced by Utkin and Vadim [2] as a unique kind of variable structure control. In addition to rejecting chattering in the control system input, Huynh et al.'s suggested second-order integral sliding mode control (SOISMC) law also ensures the durability of the multi-area strength network, which affects parametric unpredictability like load variations and matched or mismatched uncertainties in parameters [3]. The frequency as well as voltage management ancillary facilities for electrical networks from different parts of the world were surveyed by Rebourt et al. [6]. Iracleous et al. provided a methodical approach to developing a thorough model of a control region that takes the power network's influence into consideration [7]. Two reliable decentralised proportional integral (PI) control schemes for load frequency control (LFC) with communication delays were described by Bevrani et al. [8]. The work of Frunt et al. was based on the basic hypothesis that a substantial portion of the future power system will be distributed generation (DG) with a high percentage of renewable energy based sources [9]. According to Cam's comparison analysis, the suggested FGPI controller outperforms the traditional PI controller in terms of performance. A simulation was used to compare the study's findings [10]. Lee et al. presented a novel, robust load-frequency control (LFC) mechanism for managing nonlinear power systems with uncertainty [11]. Based on the wedge control theory, Atic et al. presented a decentralised model predictive load frequency control technique. A system model serves as the foundation for the control strategy, and optimisation is carried out at each sample interval [12].

An innovative adaptive load frequencies controller with lag dynamics, non-orthogonal mother wavelets that are as the activation function, and interconnectivity weights was proposed by Oysal et al. The controller is based on a “dynamic wavelet network (DWN) [13]”.

Design of Sliding Mode Controllers

Plant model mismatch and load disturbances can be efficiently compensated for with the help of the reliable control method known as the SMC. The sliding mode controller's goal is to pull the system's state to the surface and hold it there. The chattering phenomena of high-frequency switching makes the

application of sliding mode control (SMC) for load frequency control of power networks challenging. Actuators utilised in power systems are in grave danger because to this chattering issue in SMC.

Mathematical Model of Power System with Nonlinearities

This work develops a sliding mode controller to satisfy LFC criteria. In general, the sliding mode controller is a reliable control method that performs admirably when used to regulate systems that have fluctuating parameters and outside disturbances. Sliding mode control's primary goal is to propel the system's trajectory to the sliding surface and stay there from there. System invariance to specific uncertainties and fluctuations in parameters is ensured while the trajectory is on the surface. The primary purpose of a governor is to enhance the response of frequencies in the 20 seconds that follow disruptions (such generator losses).

The governor $G_H(s)$'s transfer function is.

$$G_H(s) = \frac{\Delta X_g(s)}{\Delta P_v(s)} = \frac{1}{1+sT_G} \quad (1)$$

For a non-reheat turbine $G_T(s)$, the transfer function is represented by.

$$G_T(s) = \frac{\Delta P_g(s)}{\Delta X_g(s)} = \frac{1}{1+sT_t} \quad (2)$$

The reheat turbine $G_{TRH}(s)$ transfer function is displayed as

$$G_{TRH}(s) = \frac{\Delta P_g(s)}{\Delta X_g(s)} = \frac{1+sK_rT_r}{(1+sT_t)(1+sT_r)} \quad (3)$$

In this case, T_r is the reheat turbine's time constant and K_r is its coefficient. The reheat turbine's linear model, which does not include the nonlinearity GRC, is displayed in equation (3). A device known as a generator is used to convert the kinetic energy of the turbine that produces steam into electrical energy.

The electrical system gains constant as well as the time constant for control area 1 are represented by K_{p1} and T_{p1} in Figure 1, while the power system gain characteristic and time constant for control area 2 are represented by K_{p2} and T_{p2} .

Area control error (ACE) and tie line energy error are described as

$$\Delta P_{tie} = \frac{2\pi T_{ij}}{s}(\Delta f_i - \Delta f_j) \quad (4)$$

The tie-line energy for area 2 can be computed as

$$\Delta \dot{P}_{tie2} = 2\pi T_{21}(\Delta f_2 - \Delta f_1) \quad (5)$$

For example, $j=1$ as $i=2$ and $j=2$ as $i=1$. All frequency failure and tie line energy error are included in the area control error (ACE). The governor is typically nonlinear in nature. As seen in Figure 1, it has a dead band feature. Since the input frequency fluctuates within a range of ± 0.036 Hz, the governor exhibits no output responses.

Practically speaking, the rate of change for power generation in the generating plants has maximum and minimum restrictions [2]. Generation rate constant (GRC) is the term used for this. The nonlinear turbine model with GRC, shown as a saturation block in Figure 1, is included. The producing rate

constant (GRC) with thermal units typically has a range of 3%/min. To prevent overcontrol, the AGC (Automatic Generation Control) sets a boundary of ± 0.0005 p.u.MW/s.

Figure 1 depicts the block diagram for employing a sliding mode controller (SMC) to control a heterogeneous interlinked two area power system.

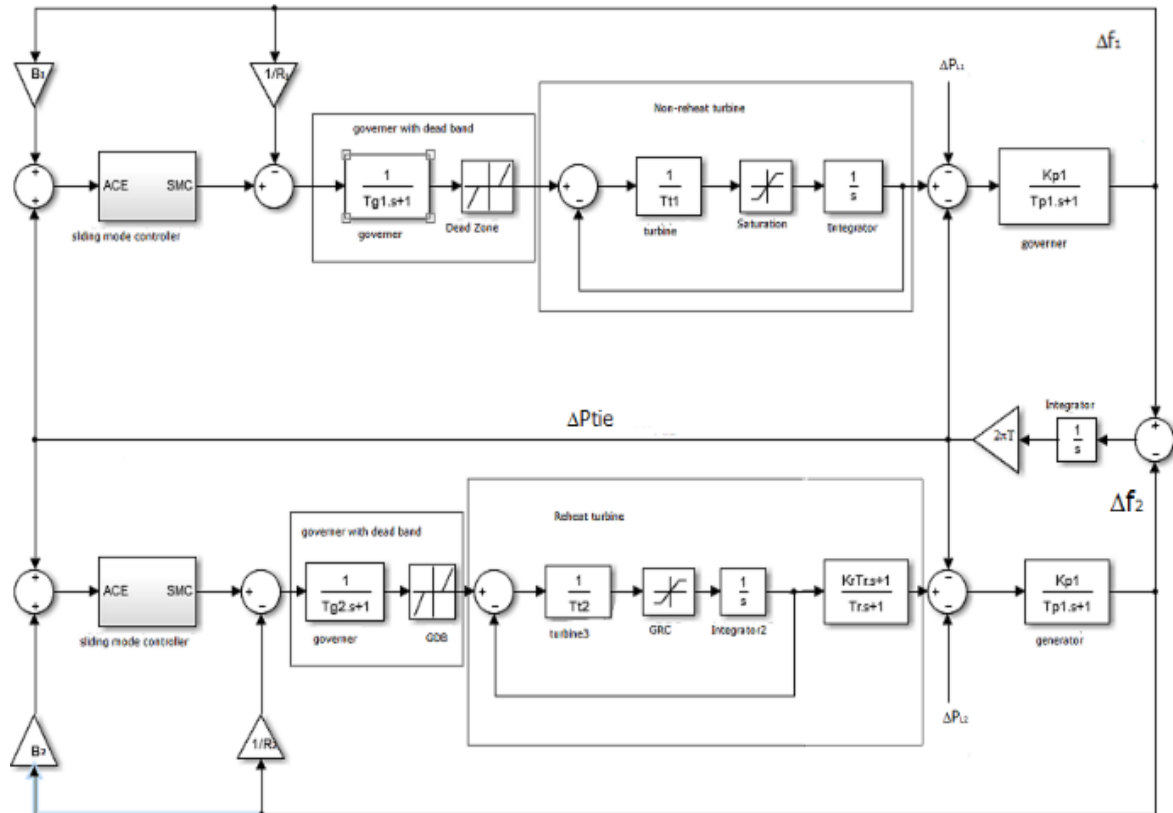


Figure 1. Block diagram for two area interconnected power system.

We suppose that zero started out with requirements for system variables and their derivatives in the creation of the mathematical equation that follows.

The ODE algorithm's formulation is

$$\Delta \dot{P}_{e1} = \left(\frac{1}{T_{n1}} \right) \Delta X_{e1} - \left(\frac{1}{T_{n1}} \right) \Delta P_{e1} \tag{5}$$

SMC Layout for the Region Featuring Non-reheat Turbine.

We identify the frequency inaccuracy in area 1 to develop the sliding mode controller (SMC) for that region using a non-reheat turbine. Based on equation (4), the connection between area 1's mismatch power and frequency inaccuracy is

$$(\Delta P_{e1} - \Delta P_{L1} - \Delta P_{re1}) \frac{K_{p1}}{T_{p1}s+1} = \Delta \omega_1 \tag{6}$$

As a result, the SMC control signal for region 1 is as

$$u_1(t) = \hat{u}_1(t) - k_1 \operatorname{sgn}(s(t)) \tag{7}$$

where k1 represents a switch controller's positive controlling gain.

SMC Plan for the Region Including a Reheat Turbine

The design of SMC with a reheating turbine for area 2 is what's being developed next. We identify the frequency inaccuracy $\Delta x_2 = \Delta f_2$ that exists in area 2. The link between the mismatched power in area 2 and the frequency error is obtained from (4) as

$$(\Delta P_{g2} - \Delta P_{l12} - \Delta P_{re2}) \frac{K_{p2}}{T_{p2}s + 1} = \Delta x_2 \quad (7)$$

SIMULATION RESULTS

Using Matlab/Simulink, we evaluate PID, fuzzy, and SMC controllers on a two-area connected electrical system. In this instance, we compare SMC with PID and fuzzy control methods. In particular, the power system model for our simulations includes nonlinearities like GRC and GDB. We decide on an upper limit GRC of 3% per minute of change and a maximum GDB of 0.036 Hz.

CONCLUSION

In this study, the two-area interlinked electrical system with non-reheat and reheat generators with non-linearities, respectively, is controlled by a sliding technique based on load frequency regulation (LFC). The power system model's block diagram includes both GRC and GDB. The main objective of this mode of sliding based LFC is to drive the area control error, tie-line power error, and frequency error to zero in both areas. On the linked power system with nonlinearities, the sliding mode control (SMC) is simulated. The simulation findings show that even with load disturbances, parameter fluctuations, and nonlinearities, the control objective is satisfactorily met. Furthermore, the system responses for load frequency control (LFC) based on sliding mode are compared to those of other controllers, such as PID-based LFC and fuzzy controlled based LFC. The simulation's findings demonstrate how resilient the sliding mode-based LFC is to PID-based LFC in terms of overshoot % and settling time. The simulation findings show that the time response of tie-line power problems displays the chattering characteristic of SMC (especially at the start of simulation). To successfully reduce the chattering effect, we intend to enhance the SMC in the future using fuzzy-based SMC and neural network-based sliding mode controllers (NN-SMC).

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