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Load frequency regulation using observer based non-linear sliding mode control

Sheetla Prasad[a,*], Shubhi Purwar[b], Nand Kishor[c]

[a] School of Electrical, Electronics and Communication Engineering, Galgotias University, Greater Noida, India
[b] Department of Electrical Engineering, Motilal Nehru National Institute of Technology, Allahabad, India
[c] Department of Engineering Sciences, University of Agder, Grimstad, Norway

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ABSTRACT

In this paper, the generalized extended state observer (GESO) and non-linear sliding mode control (SMC) are merged together to study the frequency deviation problem in multi-area power system. In study, the GESO is used not only for state and disturbance estimation but also for disturbance rejection of the system. The said observer ensures accurate estimation of the actual states leading to convergence of estimation error to zero. The non-linear SMC is used to increase the damping ratio of the system whenever, any perturbations occurs. The proposed observer based controller is compared with an existing two-layer active disturbance rejection control (ADRC) and also validated on large power system at random load disturbance. Further, the proposed controller performance is tested on the minimum and non-minimum phase systems. In addition to fast response in terms of settling time and reduced over/undershoots, the proposed control scheme satisfactorily compensates the disturbance in the system. The proposed scheme is further tested in the presence of power system non-linearities such as generation rate constraints and governor dead-band. The simulation results illustrate the robustness of proposed controller when subjected to load disturbances and non-linearities.

1. Introduction

The modern power system requires an intelligent LFC strategy to be developed in order to maintain the frequency of each area and to keep tie-line power exchange within pre-specified tolerance [1]. This led researchers to review the control techniques [2,3] for the conventional LFC scheme (PI/PID based LFC scheme [4]). In multi-area power system, the frequency deviation occurs mainly due to load disturbance. Due to the varying load composition with time, weather, temperature and uncertainty in load characteristics, it is difficult to accurately model the load for the conventional LFC studies. The secure operation of interconnected power systems with varying loads have been a challenge for the researchers [5,6].

The LFC and tie-line power flow control have become increasingly important world-wide with the aggressive development of the smart grid. In past few years, several control techniques for the LFC application have been proposed in literatures [7,8]. These studies have evolved by modifying the conventional LFC according to the changing operating conditions of the power system. In order to overcome the limitations of conventional LFC scheme, numerous techniques have been investigated and improved performance reported in the literatures [9–11]. The changing operating characteristic of generating unit requires the adjustment of servo-motor (actuator) to regulate the water/steam flow rate in the turbine. Therefore, the parameter uncertainty is an important issue in the controller design [12]. Several authors [12–14] have applied variable structure theory for the design of LFC but it has poor ability of handling system changes caused by wear and tear over prolonged use. The sliding mode control (SMC) is a form of variable structure control. The applications of SMC for LFC are given in [15,16] and the references therein. Mi et al. [15] has presented disturbance observer based sliding mode load frequency controller in presence of different load disturbances, wind power, parameter variation and generation rate constraint (GRC). Vrdoljak et al. [16] proposed a discrete-time SMC for LFC application. The non-linear switching surface [17] is applied on delay based LFC problem to improve the system dynamic performance. In most of these SMC techniques, the sliding surface is a linear combination of the system states constructed using appropriate time-invariant coefficients. As a result, sliding surface remains static even in the presence of system uncertainties, exhibiting robustness to system uncertainties. However, it leads to a sharp transient response around the equilibrium state of the system frequency.

An effort has been made by the researchers to compensate the

* Corresponding author.
E-mail address: sheetla.prasad@galgotiasuniversity.edu.in (S. Prasad).

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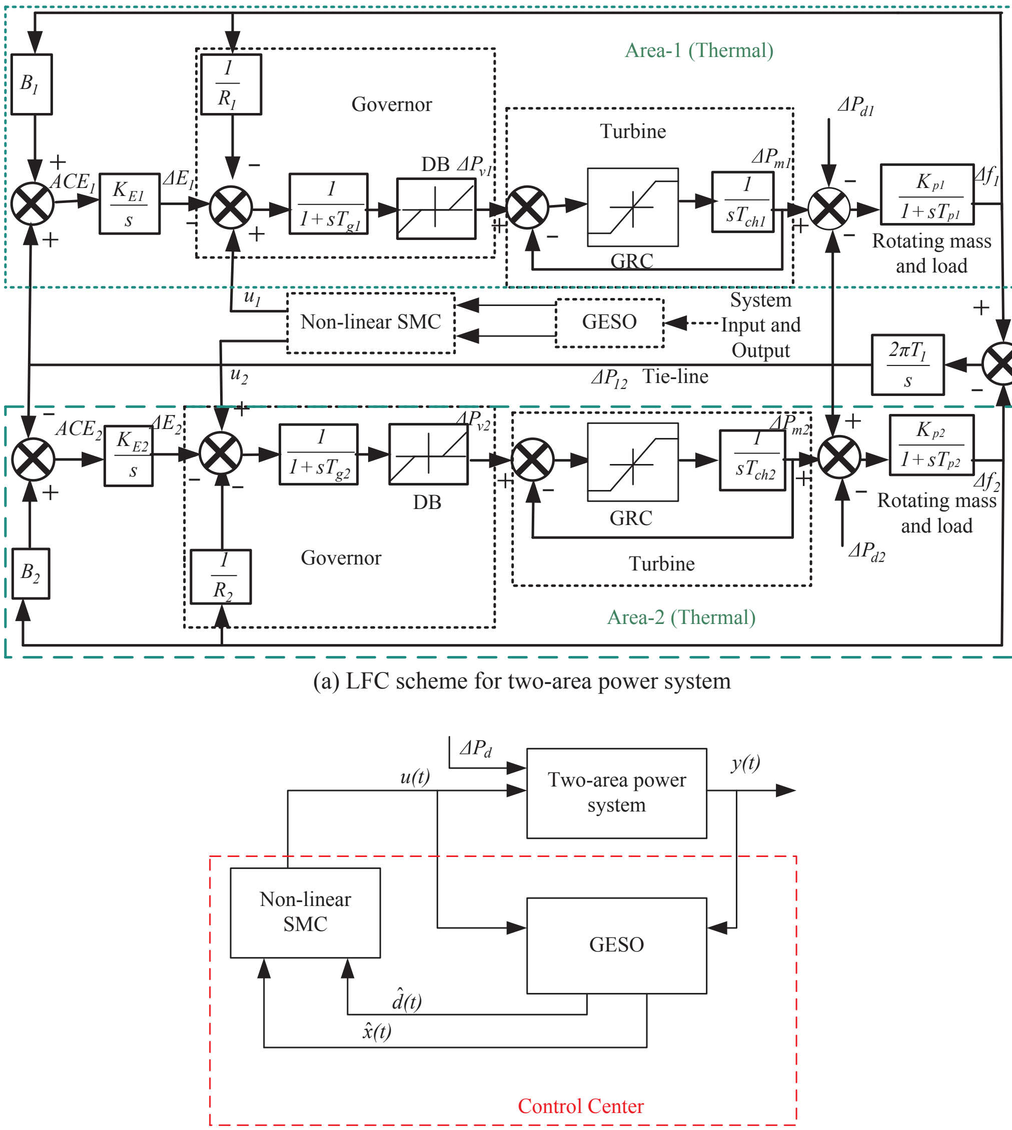

(a) LFC scheme for two-area power system

(b) Schematic diagram of the proposed control scheme

Fig. 1. LFC scheme and proposed control scheme.

uncertainties/non-linearities in the system by active disturbance rejection control (ADRC). An active disturbance rejection control [18] uses an extended state observer (ESO) to estimate and compensate the total disturbance. These disturbances are all internal uncertainties of the process dynamics and external disturbances in real time [19]. The inherent feature of ADRC is that the uncertainties and disturbances in the controlled operation of the system can be viewed as a total disturbance. Thus, it can be estimated and compensated via the ESO. The ADRC approach has achieved successful applications in real time. Due to inherent feature of disturbance rejection, ADRC becomes more popular and suitable in industries mainly for control of actuators [20,21], motion control [22], power systems [23,24], fault diagnosis [25] etc. This is due to the fact that the ESO is restrictive as (i) it can only be applied to system which can be represented by the integral chain form [18], and (ii) it can estimate the disturbances due to matched uncertainties only. A generalized extended state observer (GESO) proposed in [26], can be applied to a wider class of systems. Moreover, it is capable to estimate and compensate matched and mismatched uncertainties of the system. The two-layer ADRC [24] is designed using equivalent input disturbance (EID) compensator and internal model control (IMC). The main drawback of this approach is that stability of the closed loop depends on proper design of the low-pass filter in terms of high cut-off frequency and thus becomes more complex. The uncertainties in load disturbance of the power system affect the fixed frequency bandwidth of low-pass filter which may degrade the disturbance rejection capability or even lead to system instability. A non-linear SMC is designed in [33] assuming all states to be measurable which is not always practically possible. The effectiveness of the control scheme is verified in the presence of the uncertainties and system non-linearities. The control scheme however requires high control effort during the transient time interval.

The different control schemes in power systems assume that all the state variables are available for controller design. However, deviations in governor valve position in power system are not easy to measure. Therefore, in this paper, the states and load disturbances are estimated by the GESO and used in the design of non-linear SMC. The objective of non-linear SMC based LFC is to achieve minimum overshoot/undershoot and settling time, on the controlled output of the closed-loop system in the presence of system non-linearities/uncertainties such as GRC, GDB and different load disturbance patterns. The limitation of the control scheme presented in [33] is removed completely in this study using the LMI approach. The positive-definite matrix and final feedback

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