Available online at www.sciencedirect.com

ScienceDirect

IFAC PapersOnLine 50-1 (2017) 4388–4393

Extended Partial States Observer Based Load Frequency Control Scheme Design For Multi-area Power System Considering Wind Energy Integration

Chunyu Chen * **Kaifeng Zhang** * **Kun Yuan** * **Wei Wang** **

* *School of Automation, Southeast University, Nanjing 210096, Jiangsu, China (kaifengzhang@seu.edu.cn).*
** *Dispatching Control Center of Gansu Electric Power Corporation, Lanzhou 730050, Gansu, China*

Abstract: With the increase of wind energy integration in power systems, frequency control meets new challenges due to the uncertainty and stochasticity of wind power. In this paper, in respect to the frequency instability problem caused by disturbances of wind power, we propose an extended partial observer based load frequency control (LFC) scheme. An extended partial states observer (EPSO) is first designed to estimate both the unmeasurable states of the LFC system and wind power disturbance. And then a composite feedback controller using estimation from EPSO as well as measurable states of the LFC system itself is designed, thus attenuating the wind energy disturbance in the output channel and achieving asymptotical stability of both frequency and tie-line interchange power of the control area. The proposed LFC scheme has better feasibility to practical application since it is in essence a linear combination of measurable states values and EPSO-observed states values. Besides, it has better control performance than PI controller and saves the lengthy computational work of parameters tuning for PI controller with the aid of pole placement technique.

Keywords: Power systems stability, Modeling and simulation of power systems, Control of renewable energy resources, Load frequency control, Extended partial states observer

1. INTRODUCTION

Frequency stability is always one of the biggest concern for power grids. Since more and more renewable energy such as wind power and solar energy have been integrated into power systems. It becomes more difficult to control the frequency due to aggravated disturbance caused by the uncertainty and stochasticity of renewable energy. Therefore, it is very essential to investigate on frequency control for modern power systems with high level of renewable energy penetration.

On area control level, frequency control is usually termed load frequency control (LFC). A linear combination of deviation of both control area frequency and tie-line interchange power, known as area control error (ACE), is set as the control goal. By controlling ACE the stability of both frequency and tie-line interchange power is guaranteed. As for LFC scheme design, in addition to conventional PI based controller which is widely used in practical application Bevrani et al. (2004), many advanced control theory based schemes are proposed to improve the system robustness under parametric uncertainties or deal with system nonlinearities such as time delay or generation rate constraint (GRC) Shin et al. (2000); Yu and Tomsovic (2004); Vrdoljak et al. (2010); Shabani et al. (2013).

With the increase of the wind power in power systems, LFC scheme design considering the integration of wind power attracts more attention from researchers. More often than not, wind power is regarded as external disturbances due to its characteristics of uncertainty and stochasticity. And LFC schemes are designed to attenuate the negative influences on system stability from these disturbances. In Mi et al. (2016a), wind energy is treated as uncertain load variation and sliding mode based LFC scheme is designed for an isolated power system perturbed by wind power. In Ersdal et al. (2015), model predictive control method is utilized for a model of Nordic power system containing hydro/non-hydro generators. Wind power is also regarded as the disturbance and different disturbance scenarios considering wind power fluctuations are analyzed for the proposed LFC scheme. In Şerban and Marinescu (2011), an original aggregate electronic load controller based on a hybrid topology of a smart load is proposed for frequency control of a wind-hydro autonomous Microgrid. Both wind and hydro generators directly feed power into the grid without the use of additional power electronic interfaces. Namely, wind-hydro power is regarded as the disturbance and controllers are

⋆ This work is supported by the National Natural Science Foundation of China (No. 51577031 and No. 61473084) and Research Program of State Grid Corporation of China (Research on operation control and protection technologies of systems with large-scale renewable energy connected to the weakly-synchronized sending-end DC power grid)

2405-8963
Peer review under responsibility of International Federation of Automatic Control.
10.1016/j.ifacol.2017.08.885

only designed for BESS and smart load for microgrid stability.

In some other works, wind energy is no longer the disturbance passively alleviated by the system. By lowering the rated output power sufficiently beyond the maximum output power, affluent regulation reserve can be spared for frequency control. So wind power plants can actively participate in LFC just like other non-renewable energy based plants (e.g. thermal and hydraulic power plants) in this situation Mohamed et al. (2012); Shankar and Mukherjee (2016); Qian et al. (2016).

For scenarios where wind power is regarded as disturbances, LFC for power systems under wind energy integration boils down to controller design by alleviating influences from wind power disturbance. In recent years, disturbance observer based (DOB) LFC schemes are proposed by estimating and then attenuating the disturbance, thus achieving frequency and tie-line interchange power stability Dong et al. (2012); Tang et al. (2015); Tan et al. (2015); Mi et al. (2016b). In our previous work Chen et al. (2016), the DOB methods are improved by a disturbance rejection based (DRB) LFC scheme, where measurable states information of the system is fully used for LFC controller design. And thus control performance is improved by incorporating less observer errors. In Chen et al. (2016), unmeasurable states and disturbances are estimated by extended states observer (ESO). However, ESO estimates not only the unmeasurable but also the measurable states, which increases the dimensions of the observer and influences the control performance.

In this paper, we propose an extended partial states observer (EPSO) based LFC scheme to overcome this problem. The EPSO designed strictly estimates only the unmeasurable states and external disturbance including wind power. And then the estimation values from EPSO as well as the measurable states are used to design a composite feedback control law, thus achieving asymptotical stability of both control area frequency and tie-line interchange power.

The contribution of the paper is as follows:

(1) The proposed scheme is of simple structure. It is in essence a linear combination of estimation values from EPSO and values of measurable states of the LFC system itself, which is much simpler than other advanced control theory based controllers which usually use derivatives of the states information and complex functions.
(2) The proposed scheme fully use the measurable states of the LFC system, thus achieving better control performance than other DOB LFC schemes, which reconstruct the original LFC system and require all states of the reconstructed system observed.
(3) The proposed scheme saves control parameters tuning work with the aid of simple pole placement technique.

The remaining of the paper is organized as follows: In Section 2, the LFC model under wind power integration is built. In Section 3, firstly, EPSO is designed to estimate both the unmeasurable states and external disturbances. Then a composite feedback controller is designed with the aid of observer information from EPSO to achieve asymptotical stability of both system frequency and tie-line interchange power. In Section 4, the proposed LFC scheme is tested on a typical two-area system under wind energy integration. Eventually, the concluding remarks are given in Section 5.

2. LFC MODEL UNDER WIND POWER INTEGRATION

Before designing EPSO LFC scheme for multi-area system under wind energy integration, the wind power is firstly modelled. And then LFC model for the multi-area system is illustrated by considering wind power integration.

2.1 Wind Energy Model

The power extracted from wind turbines can be expressed by:

$$P_w = \frac{1}{2}\rho\pi R^2 V_w^3 C_P(\lambda,\beta) \tag{1}$$

where ρ is air density, R is rotor radius, V_w is wind velocity and power coefficient C_P is a nonlinear function of tip speed ratio (TSR) λ and pitch angle β. C_P can be estimated Heier (1998); Petković et al. (2013) by:

$$C_p(\lambda,\beta) = 0.5716\left(116\left(\frac{1}{\lambda-0.08\beta} - \frac{0.035}{\beta^3+1}\right) - 0.4\beta - 5\right)e^{-21\left(\frac{1}{\lambda-0.08\beta} - \frac{0.035}{\beta^3+1}\right)} + 0.0068\lambda \tag{2}$$

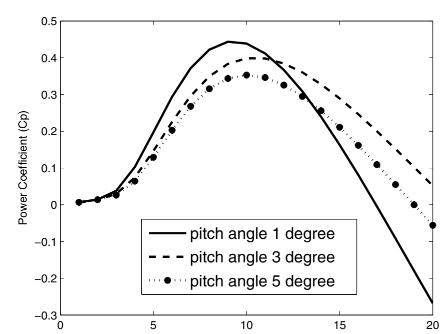

Fig. 1. Approximation of C_p - λ characteristics

Wind energy in this paper is treated as external disturbance mainly caused by the volatility of wind velocity. Based on the discussion of wind power disturbance in Section 1, wind power plants are assumed to generate at maximal capacity in this paper. Hence, it is assumed the pitch angle β, rotor radius R and air density ρ in (1) are all fixed, and the rotor speed is always controlled to make wind turbines operate at optimal TSR point to extract the maximum power. And then the characteristic of wind power totally depends on wind velocity.

$$P_w = FV_w^3 \tag{3}$$

Wind velocity in this paper is assumed to conform to Rayleigh distribution Dorvlo (2002); Jowder (2006).

$$f_{Ral}(V_w) = \frac{\pi}{2}\left(\frac{V_w}{V_m^2}\right)e^{\left(-\frac{\pi}{4}\left(\frac{V_w}{V_m}\right)^2\right)} = \frac{V_w}{\sigma^2}e^{-\frac{V_w^2}{2\sigma^2}} \tag{4}$$

where V_m is the average wind velocity. Wind velocity distribution is as shown in Fig. 2.