Energy Conversion and Management 95 (2015) 259–271

Contents lists available at ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

Linear active disturbance rejection-based load frequency control concerning high penetration of wind energy

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ARTICLE INFO

Article history:
Received 21 October 2014
Accepted 2 February 2015
Available online 27 February 2015

Keywords:
Load frequency control (LFC)
Linear active disturbance rejection control (LADRC)
Wind energy conversation system (WECS)
Doubly fed induction generator (DFIG)
Hybrid particle swarm optimization (HPSO)

ABSTRACT

A new grid load frequency control approach is proposed for the doubly fed induction generator based wind power plants. The load frequency control issue in a power system is undergoing fundamental changes due to the rapidly growing amount of wind energy conversation system, and concentrating on maintaining generation-load balance and disturbance rejection. The prominent feature of the linear active disturbance rejection control approach is that the total disturbance can be estimated and then eliminated in real time. And thus, it is a feasible solution to deal with the load frequency control issue. In this paper, the application of the linear active disturbance rejection control approach in the load frequency control issue for a complex power system with wind energy conversation system based on doubly fed induction generator is investigated. The load frequency control issue is formulated as a decentralized multi-objective optimization control problem, the solution to which is solved by the hybrid particle swarm optimization technique. To show the effectiveness of the proposed control scheme, the robust performance testing based on Monte-Carlo approach is carried out. The performance superiority of the system with the proposed linear active disturbance rejection control approach over that with the traditional proportional integral and fuzzy-proportional integral-based controllers is validated by the simulation results.

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1. Introduction

Wind power is the fastest developed energy technology and has been widely utilized in power systems [1]. Its installation capacity is growing rapidly all over the world, exceeding 318 GW at the end of year 2013 [2]. Compared with the conventional power generation approach, the controllability and availability of wind power are significantly different since the primary energy source of the wind cannot be stored and controlled [2]. Nowadays, due to the interconnection of more and more wind energy conversation system (WECS for short hereinafter), the load frequency control issue of power system has become more and more difficult than ever.

The wind power fluctuation makes a far-reaching influence on the power system frequency regulation with a high penetration of wind power. With a large number of WECS connected to the network, the imbalance between power generation and power demand will emerge, and the angular momentum of the system will be reduced. Then frequency will deviate from its nominal value [3]. The main drawback is the disconnection between some parts of system loads and generations. WECS provide dynamic frequency support by offering auxiliary frequency control. For this reason, WECS become important potential concern for the transmission system operators in the event of sudden changes in grid frequency [4]. The impact of wind power generation on system frequency response is explicitly addressed in [3].

Frequency control is vital to the power system design and operation, especially the load frequency control (LFC for short thereinafter). The aim of the LFC in a power system is to provide an acceptable high level of power quality while maintaining both voltage and frequency within tolerance limits [6]. Curtice and Reddoch analyzed the impacts of LFC caused by WECS, finding that wind power penetrations, load variations, and wind power prediction accuracy have profound influence upon control property [7]. Conventional LFC designs cannot solve the problems above, especially when the high penetration of wind power is connected to the power system. Traditional PI controller for frequency regulation is put forward in [8]. With a traditional PI controller, the control performance will degrade when the wind power penetration varies from 5% to 50% [9]. Moreover, most traditional LFC controllers are difficult to be used for large-scale power systems with nonlinearities and uncertain parameters. Afterwards a new LFC mechanism is presented, which is model predictive control (MPC), in which a certain plant is applied [10]. On the other hand, most of

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http://dx.doi.org/10.1016/j.enconman.2015.02.005
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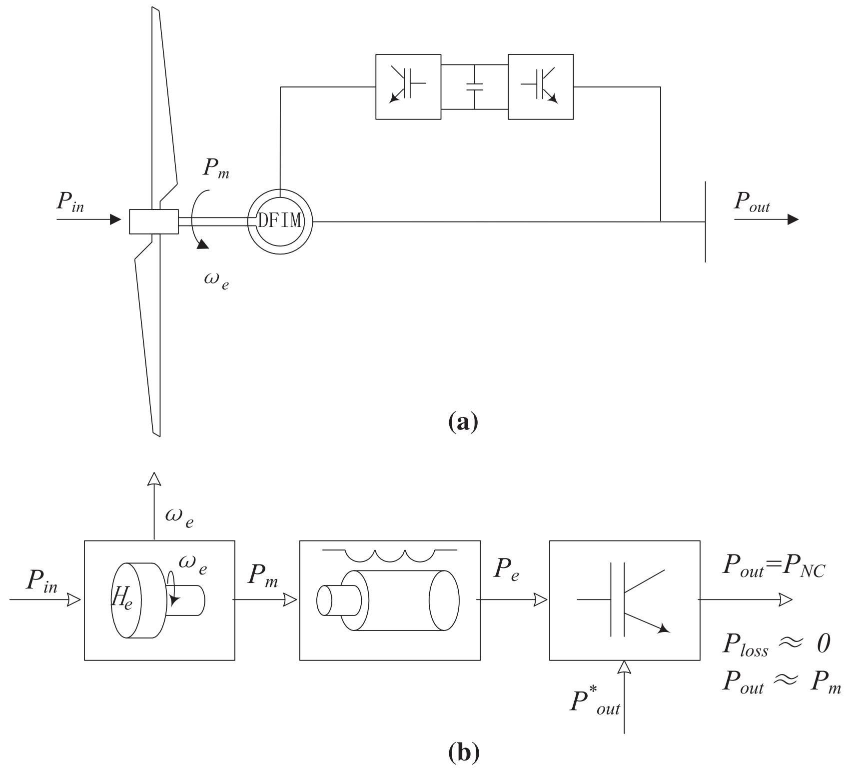

Fig. 1. (a) WECS based on doubly fed induction machines (DFIM); (b) the equivalent conversion system.

applied linear modern/robust control techniques cannot be directly employed for industry practices for the LFC problem needs more complex control structure with high-order dynamic controllers [3]. In addition, intelligent LFC schemes in the new environment are more adaptive than conventional ones, and are becoming appealing [5]. For instance, a nonlinear artificial neural network controller based on μ-synthesis to deal with the load frequency control issue of interconnected power system was proposed in [11]. The load frequency dynamic performance of two area interconnected power system was improved by employing fuzzy gain scheduling proportional and integral controllers [12]. The adaptive variable-structure controller with optimum technique was used to deal with the load frequency control issue of an interconnected power system in [13]. A PID controller optimized by ant colony optimization technique was employed in the single area load frequency control issue in [14]. The hybrid neuro-fuzzy approach was used to deal with the nonlinearities in the load frequency control issue of four area hydrothermal interconnected power system [15]. The inter-area low-frequency damping control strategies of a doubly fed induction generator-based wind farm based on the oscillation transient energy function analysis were proposed in [16], and a coordinated control method for a wind turbine generator and a battery energy storage system of a small power system were proposed in [17]. The issue of power control law synthesis in the case of a large wind system operating under full-load regime based on dynamic properties was investigated from the perspective of frequency domain in [18]. A new electromechanical energy conversion concept was introduced in wind-base power generation systems, and then the system performance was improved experimentally on a prototype system and the results of the conceptual analysis were verified in [19]. An algorithm was proposed in [20] to estimate and control the quantity of extractable kinetic energy stored in a wind farm during frequency drops. A fractional order PID controller was designed for single area load frequency control for three types of turbines, including non-reheated, reheated and hydro turbines in [21], and robustness and strong disturbance rejection ability was achieved. However, due to the nonlinearities and uncertainty of the wind power plant, an advanced and practical approach for LFC wind power plant is required.

Han proposed one alternative solution to this problem, which is named after active disturbance rejection control (ADRC) [22]. The essential idea of ADRC approach is to estimate the total disturbance with the aid of an extended state observer (ESO for short thereinafter) [23], which includes all the unmodelled dynamics of the controlled process and external disturbances in real time. Furthermore, due to the inherent disturbance rejection nature of ADRC approach, many control problems can be solved, such as multi-input multi-output systems with uncertainty [24], multivariable systems with time delay [25], variable spindle speed noncircular turning process [26], and fault diagnosis [27]. However, there are too many parameters to be tuned in the original ADRC approach if applied in industrial practices [28]. Fortunately, in order to reduce the numbers of tuning parameters, a linear ADRC (LADRC for short hereinafter) is proposed in [29]. In general, there are only two parameters to be turned: the observer bandwidth and the controller bandwidth. Because of its feasibility and simplicity, many practical engineering problems have been solved by LADRC, such as MEMS gyroscopes [30], and superconducting RF cavities [31]. The LADRC approach is employed in [32] to deal with the LFC problem in power systems with a single generator supplying power to a single service area for three types of turbines, including non-reheated, reheated, and hydro turbines. The first-order LADRC approach is used in the control of doubly fed induction generator (DFIG for short hereinafter) of a wind turbine energy conversation system [39], however, the load frequency control issue is not investigated.

In this paper, the LADRC approach will be employed to solve the LFC issue concerning high penetration of wind power both in the single-area power system and two-area power system. In order to investigate the efficiency of the proposed control strategy, a computer simulation will be conducted for the doubly fed

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