Electrical Power and Energy Systems 102 (2018) 1–10

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

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

Decentralized frequency-voltage control and stability enhancement of standalone wind turbine-load-battery

Reza Hemmati[a], Neda Azizi[a], Miadreza Shafie-khah[b], João P.S. Catalão[b,c,d,*]

[a] Department of Electrical Engineering, Kermanshah University of Technology, Kermanshah, Iran
[b] C-MAST, University of Beira Interior, 6201-001 Covilhã, Portugal
[c] INESC TEC and Faculty of Engineering of the University of Porto, 4200-465 Porto, Portugal
[d] INESC-ID, Instituto Superior Técnico, University of Lisbon, 1049-001 Lisbon, Portugal

ARTICLE INFO

Keywords:
Battery storage system
Decentralized frequency-voltage control
Induction generator
Standalone wind turbine

ABSTRACT

This paper simulates an islanding network including wind turbine, battery energy storage systems (BESS), and load. The purpose is to control voltage and frequency of the load following wind speed variations by proper control of BESS. A decentralized control scheme including two control loops is designed on BESS. One control loop is implemented for voltage regulation and the other loop is designed for frequency control. Both loops are equipped with PI (Proportional–Integral) type controllers as internal controllers. Furthermore, both loops are equipped with supplementary stabilizers as external controllers. The internal controllers regulate frequency and voltage and the external stabilizers enhance stability. This paper optimally tunes all the parameters of internal controllers and external stabilizers at the same time. The problem for tuning a large number of the design variables is mathematically expressed as a mixed integer nonlinear optimization programming and solved by modified-adaptive PSO technique. The proposed methodology is simulated on a typical standalone network including wind turbine, BESS, and load. The accurate model of BESS and wind turbine is incorporated to cope with real conditions. Moreover, in order to demonstrate the real-world results, non-linear time domain simulations are carried out in MATLAB software. The results verify that the proposed control scheme can efficiently utilize BESS to control voltage, regulate frequency, and damp out oscillations under wind and load variations.

1. Introduction

In the recent years, wind energy has shown rapid growth as a clean and inexhaustible energy source at all around the world [1]. Over year 2015, 63.5 GW new wind power generation has been added to the power grid worldwide, increasing the cumulative wind energy power to 432.9 GW. It is anticipated that by 2030, the total cumulative wind power installed worldwide reaches 1430–1933 GW [2]. However, as the penetration levels increases, it is of considerable concern that fluctuating output power of wind farms will affect the operation of the interconnected grids especially weak power systems [3,4]. Such cases may require some measures to smooth the output fluctuations to have a reliable power system [5,6]. Wind energy has many benefits, but high penetration of wind power can introduce technical challenges about grid interconnection, power quality, reliability, protection, generation dispatch, and control [7–9].

The voltage and frequency regulations are the main problems regarding control of wind turbines [10]. In wind generating system, the input mechanical power to the wind turbine changes together with wind speed variations. As a result, the electrical power produced by wind generating system comprises voltage-frequency fluctuations [11]. Such generating system cannot be connected to the electrical grid, because of its frequency-voltage fluctuations [12]. It cannot moreover supply the standalone loads, because the voltage and frequency of the load would change together with variations of load demand [12]. For instance, without proper control on voltage and frequency in the standalone mode, the voltage and frequency will decrease together with increment of load demand and they will raise accompanied by reduction of load demand [12]. As a result, a proper control is required to make the wind generating system practical in both connected to the grid [13] or standalone operation [14]. In other words, the output voltage produced by wind generators must be regulated in terms of magnitude and frequency [12].

In the standalone operation, it is necessary to present proper control strategy for wind generators to control power, voltage, and frequency [15]. The control strategy makes significant impacts on the performance of generator and interfacing converter [15,16]. Different types of generators such as induction generator and permanent magnet

* Corresponding author at: Faculty of Engineering of the University of Porto, R. Dr. Roberto Frias, Porto, Portugal.
E-mail address: catalao@ubi.pt (J.P.S. Catalão).

https://doi.org/10.1016/j.ijepes.2018.04.021
Received 3 December 2017; Received in revised form 24 March 2018; Accepted 17 April 2018
0142-0615/ © 2018 Elsevier Ltd. All rights reserved.

Nomenclature

Parameters and symbols

A	turbine swept area (m2)
c_p	performance coefficient of the turbine
c_{p_pu}	performance coefficient in pu of the maximum value of c_p
F	frequency (Hz)
k_p	power gain for $c_{p\_pu} = 1$ pu and $v_{wind\_pu} = 1$ pu, k_p is less than or equal to 1
P_m	mechanical output power of the turbine (W)
P_{m_pu}	power in pu of nominal power for particular values of ρ and A
Tm	turbine torque output
V	voltage (pu)
V_{wind}	wind speed (m/s)
V_{wind_pu}	wind speed in pu of the base wind speed
ρ	air density (kg/m^3)
β	blade pitch angle (deg)
λ	tip speed ratio of the rotor blade tip speed to wind speed

synchronous generator (PMSG) can be installed to the wind turbines [17,18]. In the standalone variable-speed wind turbine installed with PMSG, load-side converter regulates the magnitude and frequency of AC voltage and the DC voltage. On the other hand, the generator-side inverter is controlled to extract the optimal energy of wind [17,18]. Different control methods have already been applied to improve the performance of variable-speed wind turbine on the standalone operation [19].

In the above-mentioned references, various control strategies are presented to regulate both the frequency and voltage. Where, the control loops are implemented by internal controllers (such as PI type controllers) to regulate the frequency and voltage. However, these studies do not provide a separate controller (or stabilizers) to damp out the oscillations and stability improvement. In other words, they have only designed the internal controllers to regulate the frequency and voltage. Although some works have enhanced the stability of the network, this stability enhancement has not been addressed by a separate stabilizer on the control loops. As a result, current paper aims at designing separate controllers (i.e., stabilizers) in addition to the internal controllers for frequency and voltage regulation as well as stability enhancement.

One of the proper methods to cope with wind fluctuations is to utilized energy storage systems (ESS) (especially battery energy storage systems (BESS)) together with stand-alone wind units [20,21]. Similar to the renewable energy, energy storage systems (ESSs) [22] are one of the most suitable technologies in electric power systems that provide technical and economic advantages. There are several methods for storing energy such as mechanical, electro-chemical, electrical, thermal, and chemical approaches. Battery storage systems are also one of the most relevant technologies of energy storage systems that have attracted much attention in the recent years. BESS store electrical energy in the form of electrochemical process, and then the stored energy can be restored and sent back to the network. Some of the BESS applications for wind farms involve a simple scheme to charge and discharge the BESS, such as storing excess power, if the wind power output exceeds a threshold [23].

The BESS can successfully control both active and reactive powers independent of each other. In such decoupled P-Q control system, both active and reactive powers can be controlled in both directions as well as independent of each other. The decoupled P-Q control on BESS can also be supported by supplementary stabilizers to enhance network stability. The active and reactive powers have direct correlation with frequency and voltage, receptively. As a result, the P-Q control can also be implemented as decentralized frequency-voltage control system [24]. In [24], the acceptable ranges of frequency and voltage are considered as the constraints of optimization problem and the network stability is improved by such modelling.

With respect to the above conducted literature review, this paper presents a new control strategy on standalone battery-wind-load system in order to frequency-voltage control and stability enhancement at the same time. In the proposed structure, the frequency and voltage of the load are regulated by decoupled F-V control on BESS. The control loops of BESS are also equipped with supplementary stabilizers to damp out the oscillations and stability enhancement.

Although decoupled P-Q control and frequency-voltage control [24] have already been investigated by the researchers, this paper is different from the above references. In [25], the decoupled P-Q control is presented on BESS in order to regulate P (active power) and Q (reactive power) between BESS and network. But this paper presents a decupled frequency-voltage control on BESS in order to control a wind turbine. In [25], the network is not integrated with wind turbine and they do not discuss modelling and control of wind turbines. Whereas, the current paper models and discusses the wind turbine, and utilizes BESS to support the wind turbine in the standalone mode. On the other hand, the frequency-voltage control is addressed by [24] and this work also enhances the stability of the network. But Ref. [24] does not design a separate controller for stability enhancement and it presents an intelligent methodology to tune the internal controllers of BESS for stability improvement. However in the current paper, separate controllers (i.e., supplementary stabilizers) are designed in addition to the internal controllers. The proposed supplementary stabilizers are mounted on the internal control loops and they enhance the network stability.

In summary, the main contributions of the current work can be highlighted as follows;

- A decoupled frequency-voltage control on BESS is presented in order to control wind turbines. The decoupled frequency-voltage control on BESS has already been studied. But, this paper installs supplementary stabilizers on the decoupled frequency-voltage loops to enhance network stability. This is one of the main contributions of the paper. It is worth mentioning that some papers have already addressed the decoupled frequency-voltage control and stability enhancement by BESS at the same time. But they do not utilize the supplementary stabilizers on BESS. As a result, the current paper addresses a novel structure for decoupled frequency-voltage control and stability enhancement by BESS.
- The proposed decoupled frequency-voltage control and supplementary stabilizers are modelled and simulated to control wind turbines. Such structure has not been addressed on wind turbines. The decoupled frequency-voltage control has already been simulated on wind turbines. But the proposed structure including supplementary stabilizers has not been studied.
- The proposed structure regulates voltage, controls frequency, and enhances stability at the same time in the standalone wind-BESS-load system.
- All the internal controllers (voltage and frequency controllers) and supplementary stabilizers are tuned at the same time by PSO algorithm. This is also one of the main contributions of the paper. Because all the internal controllers and stabilizer are simultaneously tuned to find the most optimal operating condition of the network. The proposed methodology results in the best operation for the whole system including BESS, wind turbine, and load.
- In order to cope with real conditions, the real models of wind turbine and converter are derived and simulated. The real world modelling and nonlinear time-domain simulations are carried out in MATLAB software.

Download English Version:

https://daneshyari.com/en/article/6859180

Download Persian Version:

https://daneshyari.com/article/6859180

Daneshyari.com