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Full Length Article

Wind turbine and ultra-capacitor harvested energy increasing in microgrid using wind speed forecasting

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ABSTRACT

Wind energy source has a complex control situation because of dependence of its torque and output power on wind speed and its fluctuations. Based on this, in order to improve its control condition and dynamic efficiency, when connecting to the microgrid, ultra-capacitor which has a fast charging and discharging speed is used. Furthermore, the maximum energy derived from wind turbine and ultra-capacitor by the microgrid is of high importance which must be considered besides decreasing output power fluctuations. In this paper, for increasing the harvested energy, the Wind Speed Forecasting (WSF) model is used. So, the control method is applied by using WSF. In the proposed method, the gained energy is more than the lost energy. In fact, we increased harvested energy using a predictive control method. The considered predictive control is applied to the induction generator rotational speed variations. The considered wind turbine model in this paper produces an active power of 50 kW and is a variable speed induction generator (VSIG) with an apparent power of 50 kVA. All of the simulations are performed in MATLAB/SIMULINK software.

1. Introduction

Recently, European countries have been concerned about climate changes and have decided to reduce greenhouse gases. In this manner, they have adopted new policies to produce cleaner energies in order to reduce the produced CO_2 until 2020 by 20% and until 2050 by 50%. In this regard, increase of renewable energies and hybrid generation would be the way to reach this aim [1].

Less pollution at consumption centers, easier and less hazardous as well as more efficient transmission, controllability at generation and consumption centers and more flexibility in transformation to other energy types at consumption centers are among the factors in making electricity more attractive than other types of energy [2]. Fossil fuels such as coal, oil and natural gas and nuclear energy are non-renewable energies and their available resources are also limited. Therefore, finding new energy sources are one of the important concerns of human in recent century [3,4]. Increasing use of energy consumption, high and ever increasing cost and non-renewable nature of fossil fuels as well as bad situation of global environment have caused much attraction to environment-friendly energy resources [5]. One of the most important resources of renewable energy production is wind source.

The main problems with the energy from wind turbines are the low energy density, output power severe oscillations and uncertainty in the obtained energy from them. In order to energize all the loads, the producers must access all the required predictions about the power and energy from these resources. These predictions must have high accuracy so that no problem arises for power grid. To predict the instantaneous wind speed and increase the obtained energy from wind turbines, short term prediction must be used to control the dynamic condition of wind turbines [6].

In [7], power grid and market conditions are analyzed by predicting hourly energy from wind considering the increase of wind energy penetration level to the power grid. In [8], the authors determine the size of energy storage system in order to increase the wind energy penetration level in power network considering the grid frequency fluctuations. According to this reference, frequency deviation of power systems caused by grid-connected wind power fluctuations. In [9], calculation of the wind turbine maximum output energy in active distribution networks is elaborated and a multi-period optimal power flow analysis is proposed.

In [10], the wind turbine output power fluctuations is decreased by utilizing a new method through continuous prediction of wind speed. In this method, the wind speed in every second and continuously is predicted and by applying these predicted fluctuations to

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the grid controllers, the wind turbine output power is improved. The method proposed in [11] decreases the wind turbine output power fluctuations utilizing artificial neural network (ANN) and capacitor system controller. In this reference, an ANN controller is considered for controlling the DC-bus connected Energy Capacitor System (ECS). The authors in [12] lessen wind turbine output power fluctuations using prediction and supervisory control unit based on energy storage system. In [13], the transferred energy from wind turbine to the grid is increased using short term wind speed prediction. In [14], wind energy is increased through energy storage and demand response. In [15], scheduling of microgrid operation including wind turbines, photovoltaic systems, energy storages and responsive loads based on stochastic is analyzed. The authors in [16] elaborate the effect of short and long term prediction on the performance of energy storage system.

In [17], the author presents maximizing profit of wind-battery supported power station based on wind power and energy price forecasting. In [1,18–20], precise models of wind turbine controllers design are presented in order to improve dynamic condition. Reference [21] dynamically simulates the wind turbine and hybrid energy systems.

Considering the aforementioned explanations, in the second section of this paper, design and modelling of wind turbine, ultra-capacitor energy storage system and the procedure of connecting wind turbine and ultra-capacitor to the microgrid and also modelling of the wind speed forecasting system are elaborated. In the third section, some explanations about the control process of wind turbine blade's angle control and also the specifications of the control system of connection of ultra-capacitor to the DC link are presented. In section four, increase of obtained energy using the predictive control is conducted. In section five, simulation results for the condition with and without predictive control are demonstrated. Finally, the paper is concluded in section six.

2. Design and modeling

2.1. Wind turbine specifications

In general condition, the mathematical formulation of extraction power of wind energy using momentum theory is expressed by (1) and (2) [22]:

$$P_{wind} = \frac{1}{2}\rho A v^3 = \frac{1}{2}\rho \pi R^2 v^3 \quad (1)$$

where, ρ is air density in kg/m^3, A is the swept area of the rotor in m^2, R is the radius of swept area in meter and v is the wind speed in m/s. Therefore, the wind turbine obtainable power can be expressed by (2):

$$P_t = \frac{1}{2}\rho \pi R^2 v^3 C_p(\lambda, \theta) \quad (2)$$

In this equation, C_P is the power coefficient of the wind turbine. This value is related to tip speed ratio (TSR) and wind turbine blade pitch angle. The ratio of tip speed ratio to wind speed is demonstrated by λ which is dimensionless and is expressed by (3):

$$TSR = \lambda = \frac{R \times \omega_r}{V_{wind}} \quad (3)$$

where, V_{wind} is the wind speed, R is the blade radius and ω_r is the angular speed at the wind turbine blades. The wind speeds lower than the rated wind speed utilize the Maximum Power Point Tracking (MPPT) strategy through controlling rotor speed and making TSR constant in its optimum value. Furthermore, for the wind speeds more than rated wind speed, the strategy of limiting power is gained via controlling blades pitch angle.

2.2. Ultra-capacitor specifications

Different ultra-capacitor models have been presented up to now. Some of these models are merely for analyzing the ultra-capacitor itself and obtaining thermal and electrical characteristics of it [23]. These models are only appropriate for analyzing the characteristics of ultra-capacitors and are not efficient for analyzing in electrical grids due to their complexity. An example of extended model of ultra-capacitor is shown in Fig. 1a. This ultra-capacitor model is analyzed in [11] and its aim is to smooth the output power of wind turbine. The proposed model in [24] is presented in Fig. 1b. The same model is used in this paper.

In this paper, a 2F (Farad) ultra-capacitor with an internal resistance of 1.5 mΩ is used. Each of the ultra-capacitor's cells has the initial voltage of 50 V which is placed in 16 in series to reveal an initial voltage of 800 V. The capacity of the series is 0.125F.

2.3. System specifications of the grid

System specifications of the grid with the connection of wind turbine and ultra-capacitor energy storage system are demonstrated in Fig. 2 [10,25]. As shown, wind turbine and ultra-capacitor system are connected to a microgrid with a weak network. This microgrid is severely reacting against power fluctuations and transferred energy. Based on this, controlling power and output energy of wind turbine in this condition is of high importance. In Fig. 2, the combination of wind turbine, ultra-capacitor energy storage and microgrid supply AC and DC loads.

2.4. The prediction system specifications

The prediction method depends on the available data and data's time period. In wind turbines dynamic control, data are wind speed and data's time periods are the seconds. On this bases, the forecasting method of wind speed in this paper is the linear forecasting method [10,26]. This method can properly handle data of wind speed in a short time period. This prediction control method is demonstrated in Fig. 3. According to this figure, having the previous changed time (t_0) and the changed predicted time ($t_0 + T$), the variation rate is obtained as expressed by (4). Afterwards, having the rate from (4), the line equation obtained in (5) can be calculated.

$$V(t) = m((t_0 + T) - t_0) + V(t_0) \Rightarrow V(t) = mT + V(t_0) \quad (4)$$

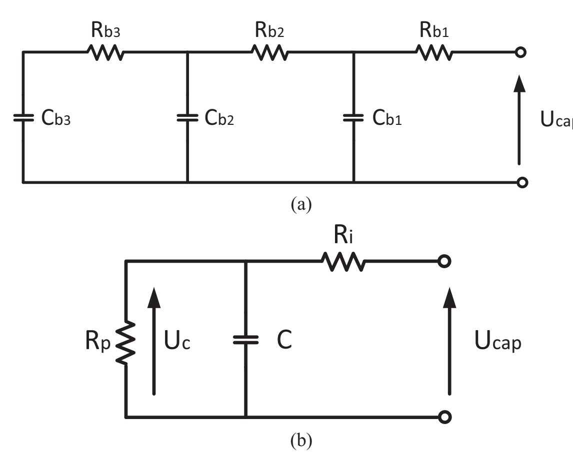

Fig. 1. Ultra-capacitor modelling (a) The extended equivalent model of ultra-capacitor based on [11] (b) The compact equivalent model of ultra-capacitor based on [24].