

Constant Control of the Power of DFIG Wind Turbines

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ABSTRACT

With the increasing penetration of wind energy into electricity grids, energy storage will be required to dynamically adapt to the intermittency of wind energy. This article proposes a new two-stage constant power control system for a wind farm equipped with Dual Induction Generator (DFIG) wind turbines. Each DFIG wind turbine is equipped with a super capacitor energy storage (ESS) system and is controlled by low level wind turbines (WTG) and coordinated by a higher level wind farm monitoring control system (WFSC). The WFSC generates the actual power references for the lower layer WTG commands based on the actual power demand of the network operator or the corresponding production commitment. The WKA lower layer regulators then control each DFIG wind turbine to produce the desired amount of active power, balancing the gaps between available wind energy and the desired active power through the SSE. In PSCAD / EMTDC, simulation studies will be carried out in a wind farm with 15 DFIG wind turbines to verify the effectiveness of the proposed regulatory system.

KEYWORDS: Constant power control (CPC), doubly fed induction generator (DFIG), energy storage, supervisory controller, wind turbine

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I. WIND TURBINE

Generators (WTG) are normally controlled to produce maximum electrical power from wind under normal wind conditions. However, due to variations in wind speed, the electrical power generated by a WEA generally varies. Currently, wind energy supplies only about 1% to 2% of the US power supply. At such a level of penetration, it is not necessary to require WEA to participate in automatic production control, unit commitment or frequency regulation. However, it is expected that wind energy will make an important contribution to the country's and the world's electricity supply over the next three decades. For example, the European Wind Energy Association has set itself the target of covering more than 22% of Europe's electricity needs with wind energy by 2030 [1]. In the United States, according to a report [2] from the Department of Energy, 20% of the wind power produced in the country by 2030 is possible. With such a high penetration, this will be the case for WEAs to provide a desired amount of real power to participate in automatic generation control or grid frequency control [3]. The interruption of wind resources, however, can lead to high rates of change (ramps) in energy production [4], which is a crucial problem for the balance of energy systems. Moreover, in order to optimize the economic performance of high wind energy transmission electrical systems, it would be desirable to require the operators of production networks to participate in the unit's commitment, economic distribution or energy production. Operation of the electricity market [5]. In practice, a short

term wind energy forecast [6] is performed to assist WEA in performing these functions.

However, prediction errors are also present with the methods of the prior art [5]. In these circumstances, the reserve current is supplied by reserves, which may, however, be more expensive than the basic electricity prices [7]. In order for wind turbines to participate effectively in the regulation of frequency and active power, the participation of power plants, the economic distribution and functioning of the electricity market, energy storage devices must be adapted from dynamic way to the interaction of wind energy. In [8], the authors examined and compared various possible technologies for storing electrical energy for the intermittent production of renewable energies, such as wind energy. Pumped water and compressed air are currently the most widely used energy storage technologies for power grids because of their low capital costs [9]. However, these two technologies are highly dependent on geographical location with a relatively low return flight efficiency. Batteries and supercapacitors are more efficient than their competitors, react more quickly to fluctuations in demand, and are easy to develop and deploy anywhere. Supercapacitors have a higher power density, higher efficiency, longer life, and lower capital cost per cycle than batteries [10]. As a result, supercapacitors are a good candidate for short-term energy storage (ie seconds to minutes) that allows WEAs to perform the frequency

regulation function and participate effectively. the commitment of the unit and the functioning of the energy market. Some researchers have studied the use of supercapacitors [10] or batteries [11] - [13] as energy reserves for wind turbines. However, these studies have focused solely on the management and operation of

individual wind turbines and have not examined aspects of wind turbines in order to participate in the regulation of the network. This article proposes a new two-layer Constant Power Control (CPC) system for a DFIG dual-power wind farm [14], in which each wind turbine is equipped with a Super Capacitor Energy Storage System (ESS).

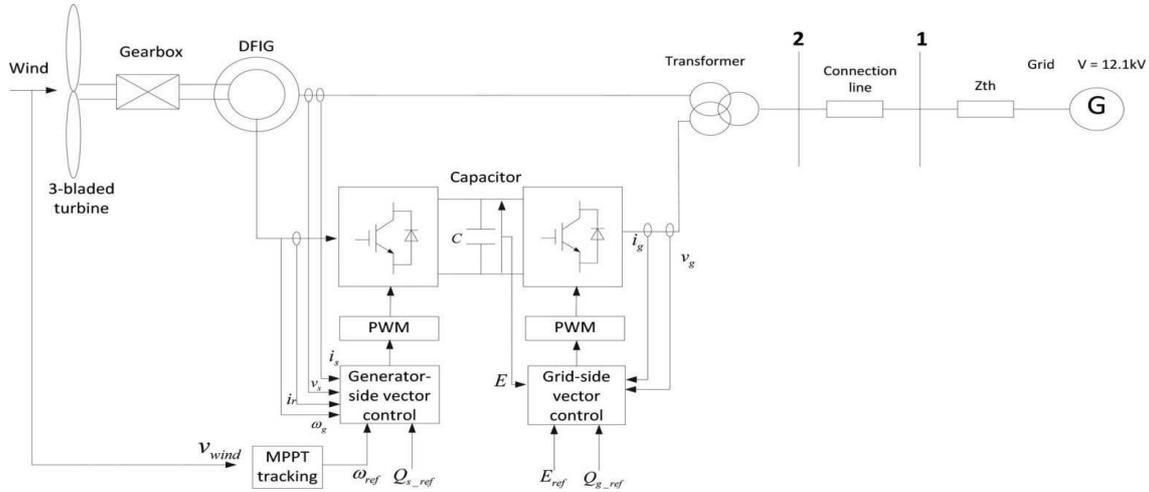


Fig.1. Configuration of a DFIG wind turbine equipped with connected to a power grid.

The CPC includes a WFSC (Top Layer Wind Park Monitoring Controller) and a WTG Lower Layer Controller. The upper layer WFSC generates the active power references for the lower layer WTG controllers of each DFIG wind turbine as a function of the active power demand from the network manager. The lower layer WKA regulators then control each DFIG wind turbine to produce the desired amount of active power, thereby balancing the gaps between the available wind energy and the desired active power through the ESS. In PSCAD / EMTDC simulation studies will be carried out for a wind farm with 15 DFIG wind turbines to verify the effectiveness of the proposed control scheme.

II. DFIG WIND TURBINE WITH ENERGY STORAGE

Figure 1 shows the basic configuration of a DFIG wind turbine equipped with an ESS based on a supercapacitor. The low speed turbine feeds DFIG at high speed via a transmission. The DFIG is an induction machine with a winding rotor. It is connected to the power supply at both the stator and rotor terminals. The stator is directly connected to the network while the rotor is powered by a frequency converter consisting of a rotor-side converter (RSC) and a gate-side converter (GSC), connected via a DC connection and one behind the other generally having a fractional denomination (25% to 30%) of the DFIG rating. As a result, the wind turbine can operate at a speed of the order of $\pm 25\%$ to 30% around the synchronous speed and its real and reactive power can be controlled independently. In this work, an ESS consisting of a group of supercapacitors and a two-quadrant DC-DC converter is connected to the DC link of the DFIG converters. The ESS serves either as a source or sink for the actual power and therefore contributes to the control of the actual power generated by the wind turbine. The value of the bank of supercapacitors can be determined by

$$C_{ess} = 2P_nT / V_{2SC} \quad (1)$$

If C_{ess} is specified in Farad, P_n is the power rating of the DFIG in watts, V_{2SC} is the voltage of the supercapacitor battery in volts, and T is the desired time in seconds that the

ESS can supply / store. energy at the nominal power (P_n) of the DFIG. There are two reasons for using an ESS in each wind turbine instead of a large central ESS for the entire wind farm. First, this configuration is very reliable because the failure of a single ESS unit will not affect the ESS units of another evaluation unit. Secondly, the use of an ESS in each WEA can improve the DC bus of the DFIG converters during transients by improving the low-voltage bridging capability of the WEA [10].

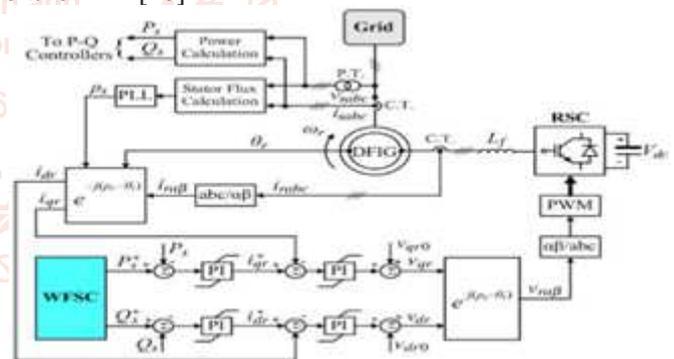


Fig.2. Overall vector control scheme of the RSC

III. WIND TURBINE CONTROL AND FLICKER EMISSION ANALYSIS

In a DFIG based variable speed wind turbine, the control target differs depending on the wind speed. At low wind speeds, the goal of the controller is to maintain the optimum top speed ratio to capture the maximum wind power. When the wind speed is high, the aim of the control is to keep the power drawn constant at its nominal value, since the available power exceeds the capacity of the wind turbine that could overload the system.

A. Control of Back-to-Back Converter

Vector control techniques are the most commonly used methods for a back-to-back converter in a wind turbine. Two vector control schemes for the RSC and the GSC are illustrated, as shown in Figure 1, where v_s and the stator voltage and current are, i_r is the rotor current, v_g is the mains voltage and i_g are the current of the GSC, w_g is the

speed of the generator, E the intermediate circuit voltage, $P_{s\text{ref}}$ and $Q_{s\text{ref}}$ are the reference values of the active and reactive power of the stator, $Q_{r\text{ref}}$ is the reference value of the reactive power flow between the sector and GSC, E_{ref} is the reference value of the intermediate circuit voltage C is of the intermediate circuit capacitor. The objective of vector control for RSC is to implement maximum monitoring of wind energy by controlling the electric torque of DFIG. The reference value of the speed of the generator ω_{ref} is obtained a lookup table to get the best possible peak speed ratio. The goal of the GSC is to keep the DC link voltage constant while maintaining the main sinusoidal currents. It can also be responsible for controlling the reactive power flow between the network and the grid-side converter by adjusting $Q_{g\text{ref}}$. Normally, the reactive power values of RSC and GSC are set to zero to provide unit power factor operation and to reduce the RSC and GSC current.

B. Pitch Control

Normally, pitch control is used to limit the aerodynamic power sensed by the wind. When the wind speed is low, the wind turbine should simply try to generate as much power as possible. It is therefore not necessary to shake the blades. With wind speeds above the nominal value, the pitch control is responsible for the power limitation.

The PI knob that adjusts the tilt angles works well in normal operation. However, the performance of the pitch control system degrades when a rapid change in wind speed from low to high is exerted on the rotor of the turbine. A positive power error contribution takes a lot of time to negate the effects of the negative pitch angle contribution generated by the integration of these negative power errors.

This prevents the built-in power error from accumulating when the rotor is running at low wind speed. The value of K_{aw} may depend on the turbine. If the tilt angle is not saturated, this anti-turn return term is zero.

IV. SIMULATION RESULTS

For a wind farm with 15 DFIG wind turbines, simulation studies will be conducted to verify the effectiveness of the proposed regulatory system under different operating conditions. Each DFIG wind turbine (see Fig. 1) has a capacity of 3.6 MW [14], [15]. The total capacity of the wind farm is 54 MW. Each DFIG wind turbine is connected to the wind farm's internal network via a 4.16 / 34.5 kV step-up transformer. The high voltage terminals of all wind farm transformers are connected via 34.5 kV power cables to the wind farm's internal network. The entire wind farm is connected to the public grid via a boost boost of 34.5 / 138 kV on the CCP to provide reactive and real energy P and Q . In this article, the power grid is represented by a source infinite. The ESS of each wind turbine is designed to continuously deliver / store 20% of the DFIG power rating for approximately 60 seconds. Then you can get the total capacity of the bank of supercapacitors from (1). The parameters of the wind turbine, the ESS and the power grid are listed in the appendix. Some typical results are presented and discussed in this section.

It shows the wind speed profiles of WTG1 (v_{w1}), WTG6 (v_{w6}) and WTG11 (v_{w11}). The wind speed in the three wind turbines varies within a range of ± 3 m / s around their average value of 12 m / s. Variations in wind speed cause

variations in the electrical quantities of the wind turbine. As shown in Figure 11, changes in wind speed in the wind farm cause significant variations in the total active power of the CCP when it is not equipped with energy storage devices or the CPC system. offers. The performance of the wind farm differs significantly from the active power requirement or the performance commitment. In future power grids where wind penetration is high (eg 20%), such variations in real power can pose serious problems for grid operation.

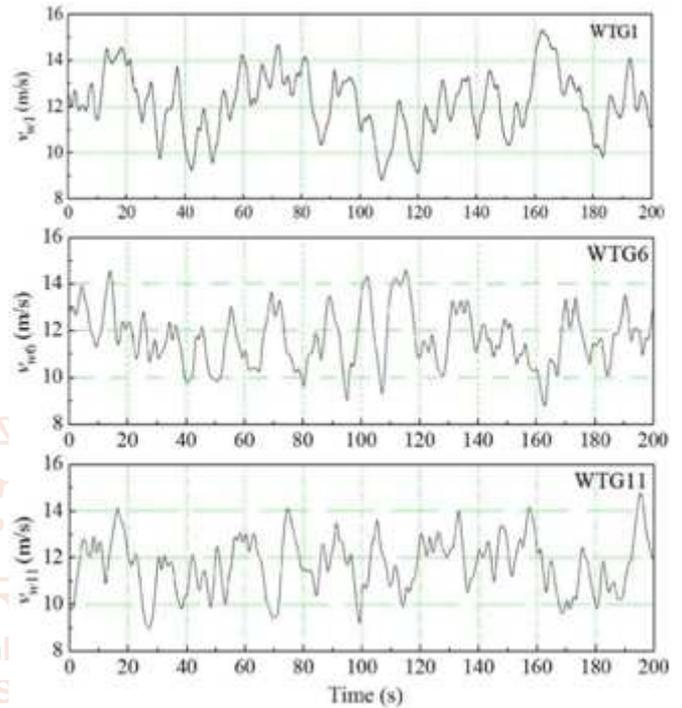


Fig.3. Wind speed profiles of WTG1, WTG6, and WTG11

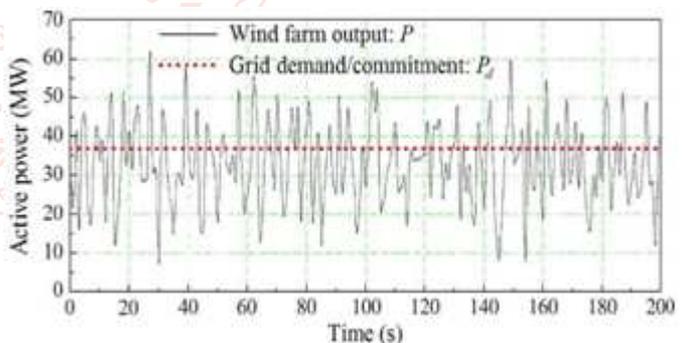


Fig.4. Comparison of the wind farm power output and the constant power demand from or commitment to the grid operator: Without ESSs and the proposed CPC scheme.

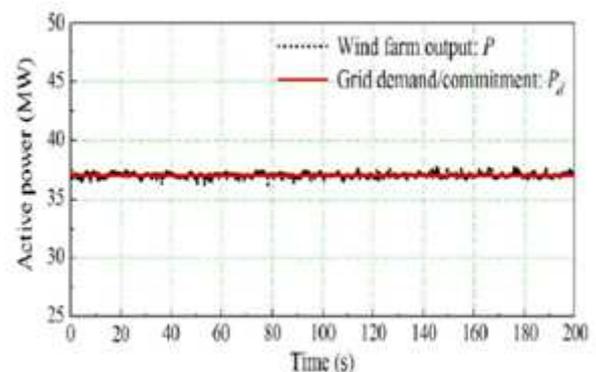


Fig.5. Comparison of the wind farm power output and the constant power demand from or commitment to the grid operator: With the proposed CPC scheme.

Here, the total active power of the wind farm is compared with the electricity requirement or the obligation of the grid operator, whereby each wind turbine is equipped with an ESS (see Figure 1). The ESS stores energy when the wind turbine generates more real power than demand / commitment and provides power when the wind turbine generates less power than demand / commitment. The resulting power of the wind farm is therefore regulated to a constant value required by the grid operator.

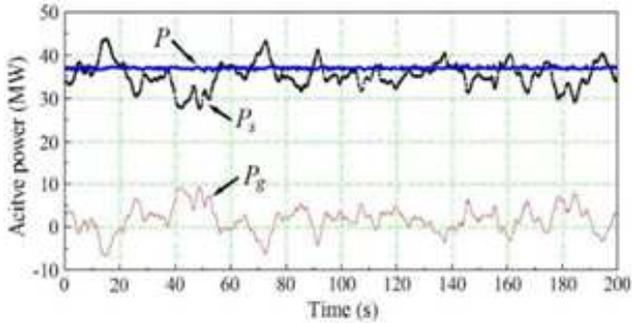


Fig.6. Active powers of all WTGs and the wind farm

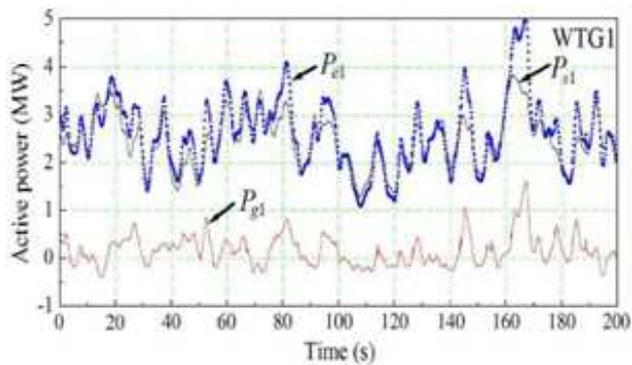


Fig.7. Stator active power (P_{s1}), GSC active power (P_{g1}), and total active power output (P_{e1}) of WTG1.

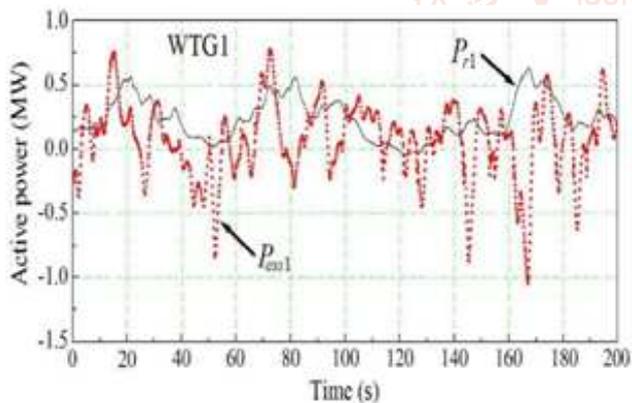


Fig.8. Rotor active power (P_{r1}) and active power stored in or supplied by the ESS (P_{ess1}) of WTG1.

The total active power of the stator P_s and the total active power of the CGC P_g of all the wind turbines, as well as the total active power output P (measured at the CCP) of the wind farm. By controlling the proposed CPC scheme, the variations in the active power of the stator are exactly compensated by the variations in the active power of the GSC. As a result, the total active power of the wind farm is constant. However, the total active output power P_{ei} of each WEA, which is the sum of the active power of the stator P_{si} and the active power GSC P_{gi} , is generally not constant, as shown in Figure 1 for WEA. The differences between the active power RSC (P_{ri}) and the active power GSC (P_{gi}) of

each WTG are stored in or supplied by the ESS (P_{essi}) as shown in Figure 8 for the WTG 1.

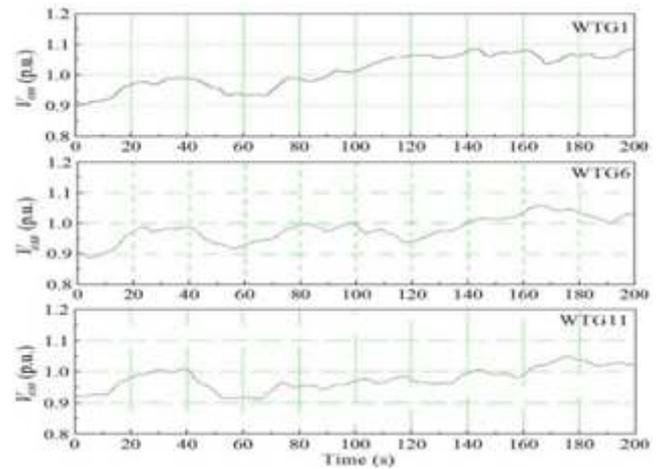


Fig.9. Voltages of the super capacitor banks of WTG1, WTG6, and WTG11

V. CONCLUSION

This article proposes a new two-layer CPC system for a wind farm equipped with DFIG wind turbines. Each wind turbine is equipped with an ESS based on a super capacitor connected to the continuous DFIG connection via a two-quadrant DC-DC converter. The ESS serves as a source or sink for real power to control the actual power generated by the DFIG wind turbine. Each DFIG wind turbine and its ESS system are controlled by lower layer WEA controllers, coordinated by a higher layer WFSC, to produce constant active power required or provided by the network manager. In this article, a comparison was made between two different techniques of height control. Conventional single height control has been replaced by a height control technique based on fuzzy logic control. To reduce flicker, there is an IPC control scheme before. This paper proposes the implementation of fuzzy logic control in tilt angle control for DFIG-based wind energy conversion. The fuzzy logic control is based on the mamdani-25 rules. It effectively controls the pitch angle to get a better response from the power generation and to keep the voltage generation at a constant level. The proposed model for simulation and modeling is designed in the Matlab / Simulink software. The results of the simulation show that the fuzzy controller effectively controls the angle of inclination of the wind turbine. It has also been observed that the proposed fuzzy controller is more efficient than the conventional IPC scheme.

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