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Simulation & Performence Analysis Of Multiple Wind Turbine with ESS

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ABSTRACT:Wind turbine generators (WTGs) are usually controlled to generate maximum electrical power from wind under normal wind conditions. With the increasing penetration of wind power into electric power grids, energy storage devices will be required to dynamically match the intermittency of wind energy.

This paper presents the performance analysis of two-layer constant-power control (CPC) scheme for a wind farm equipped with doubly fed induction generator (DFIG) wind turbines, where each WTG is equipped with a super capacitor energy storage system (ESS). To meet the requirements of frequency and active power regulation, energy storage devices will be required to dynamically match the intermittency of wind energy. In the two layer control, there is a high layer controller known as Wind farm supervisory control (WFSC), which generates Active power (P), Stator power (Ps), Energy storage power (Pe), DC voltage (Vdc) etc. references for the low layer Wind turbine generator (WTG) controllers, according to the power demand from the grid operator. The low layer wind turbine generator(WTG) controller consist of Rotor side converter control and Grid side converter control to regulate each Double fed induction generator (DFIG) wind turbine, to generate desired amount of active power, Where the deviations between the available wind energy input and desired active power output are compensated by Super capacitor Energy storage system. Simulation are carried out in MATLAB on a wind farm equipped with multiple DFIG wind turbines to verify the effectiveness of the proposed control scheme.

KEYWORDS: Constant power control (CPC), Super-capacitor Energy storage system, Wind farm supervisory control, Wind Turbine Generator Contollers, doubly fed induction generator (DFIG).

I.INTRODUCTION

Wind turbine generators (WTGs) are usually controlled to generate maximum electrical power from wind under normal wind conditions. However, because of the variations of wind speed, the generated electrical power of a WTG is usually fluctuated. Currently, wind energy provides about 1%–2% of the world‘s electricity supply. At such a penetration level, it is not necessary to require WTGs to participate in automatic generation control, unit commitment, or frequency regulation. However, it is reasonable to expect that wind power will be capable of becoming a major contributor to the nation’s and world’s electricity supply over the next three decades.

At such high levels of penetration, it will become necessary to require WTGs to supply a desired amount of active power to participate in automatic generation control or frequency regulation of the grid [3]. However, the intermittency of wind resources can cause high rates of change (ramps) in power generation [4], which is a critical issue for balancing power systems. Moreover, to optimize the economic performance of power systems with high penetrations of wind power, it would be desired to require WTGs to participate in unit commitment, economic dispatch, or electricity market operation [5]. In practice, short-term wind power prediction [6] is carried out to help WTGs provide these functions. However, even using the state-of-the-art methods, prediction errors are present [5]. Under these conditions, the replacement power is supported by reserves, which, however, can be more expensive than base electricity prices [7]. To enable WTGs to effectively participate in frequency and active power regulation, unit commitment, economic dispatch, and electricity market operation, energy storage devices will be required to dynamically match the intermittency of wind energy.

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This paper proposes a novel two-layer constant power control (CPC) scheme for a wind farm equipped with doubly fed induction generator (DFIG) wind turbines [14], where each WTG is equipped with a super-capacitor energy storage system (ESS).

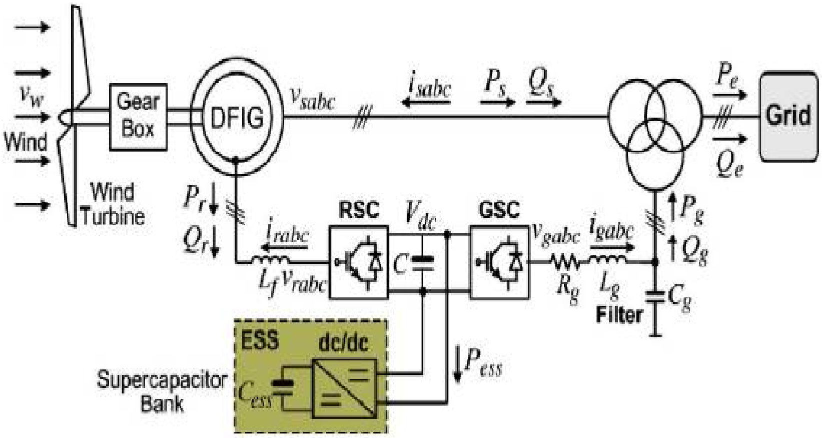

Fig. 1. Configuration of a DFIG wind turbine equipped with a supercapacitor ESS connected to a power grid.

The CPC consists of a high-layer wind farm supervisory controller (WFSC) and low-layer WTG controllers. The high layer WFSC generates the active power references for the low layer WTG controllers of each DFIG wind turbine according to the active power demand from the grid operator. The low-layer WTG controllers then regulate each DFIG wind turbine to generate the desired amount of active power, where the deviations between the available wind energy input and desired active power output are compensated by the ESS. Simulation studies are carried out in MATLAB for a wind farm equipped with multiple DFIG wind turbines to verify the effectiveness of the proposed control scheme.

II. MODELLING OF WIND TURBINE

The mechanical power of the turbine is given by:

$$P_m = ½ \rho A u^3 c_p \qquad (1)$$

where *Pm* is the power extracted from the airflow, ρ is the air density, *A* is the area covered by the rotor, *u* is the wind speed upstream of the rotor, and c_p is the performance coefficient or power coefficient.
The power coefficient is a function of the pitch angle of rotor blades θ and of the tip speed ratio λ, which is the ratio between blade tip speed and wind speed upstream of the rotor.
The computation of the power coefficient requires the use of blade element theory and the knowledge of blade geometry. We consider the blade geometry using the numerical approximation developed in [7], assuming that the power coefficient is given by:

$$C_p = 0.73\lambda_i e^{-18.4/\lambda_{ii}} \qquad (2)$$

where λ_i and λ_{ii} are respectively given by:

$$\lambda_i = 151/ \lambda_{ii} – 0.58\theta – 0.002\ \theta^{2.14} -13.2 \qquad (3)$$

$$\lambda_{ii} = 1/ [\ 1/(\lambda – 0.02\theta) – 0.003/(\theta^3+1)] \qquad (4)$$

The maximum power coefficient is given for a null pitch angle and is equal to:

$$C_{pmax} = 0.4412 \qquad (5)$$

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where the optimum tip speed ratio is equal to:

$$\lambda opt = 7.057 \tag{6}$$

The power coefficient is illustrated in Figure 2.1 as a function of the tip speed ratio.

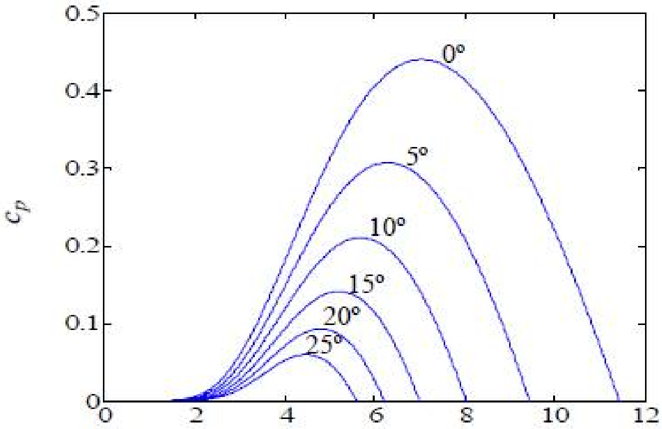

Fig. 2.1. Power coefficient curves versus tip speed ratio

The mechanical power extracted from the wind is modelled by (1) to (4). The equations for modelling rotor motion are given by:

$$\frac{d\omega m}{dt} = 1/J_m\,(T_m - T_{dm} - T_{am} - T_{elas}) \tag{7}$$

$$\frac{d\omega e}{dt} = 1/J_e\,(T_{elas} - T_{de} - T_{ae} - T_e) \tag{8}$$

Where ω_m is the rotor speed of turbine, J_m is turbine moment of inertia, T_m is the mechanical torque, T_{dm} is the resistant torque in the turbine bearing, T_{am} is the resistant torque in the hub and blades due to the viscosity of the airflow, T_{elas} is the torque of the torsional stiffness, ω_e is the rotor speed of the electric machine, Je is the electric machine moment of inertia, T_{de} is the resistant torque in electric machine bearing, T_{ae} is the resistant torque due to the viscosity of the airflow in the electric machine, and Te is the electric torque. The equations for modelling a permanent magnetic synchronous machine, PMSM, can be found in diverse literature; using the motor machine convention, the following set of equations is considered:

$$\frac{did}{dt} = 1/L_d\,(u_d - p\omega_e L_q i_q - R_d i_d) \tag{9}$$

$$\frac{diq}{dt} = 1/L_q\,(u_q - p\omega_e\,(L_q i_q + M i_f) - R_q i_q) \tag{10}$$

where i_f is the equivalent rotor current, M is the mutual inductance, p is the number of pairs of poles; and where in $d\ q$ axes id and iq are the stator currents, Ld and Lq are the stator inductances, Rd and Rq are the stator resistances, ud and uq are the stator voltages. A unity power factor is imposed to the electric machine, implying a null Qe . The electric power Pe is given by:

$$P_e = [\ u_d\ u_q\ u_f]\ [i_d\ i_q\ i_f\ ]^T \tag{11}$$

The output power injected in the electric network characterized by P and Q in α β axes is given by:

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$$\begin{bmatrix} P \\ Q \end{bmatrix} = \begin{bmatrix} u_\alpha & u_\beta \\ -u_\beta & u_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix}$$

where in α β axes, $i_\alpha$and $i_\beta$are the phase currents, $u_\alpha$and $u_\beta$are the phase voltages. The apparent output power is given by:

$$S = (P^2 + Q^2 + H^2)^{1/2} \quad (12)$$

where H is the harmonic power.

III.DFIG WIND TURBINE WITH ENERGY STORAGE SYSTEM

Fig. 3.1 shows the basic configuration of a DFIG wind turbine equipped with a supercapacitor-based ESS. The low-speed wind turbine drives a high-speed DFIG through a gearbox. The DFIG is a wound-rotor induction machine. It is connected to the power grid at both stator and rotor terminals. The stator is directly connected to the grid, while the rotor is fed through a variable-frequency converter, which consists of a rotor-side converter (RSC) and a grid-side converter (GSC) connected back to back through a dc link and usually has a rating of a fraction (25%–30%) of the DFIG nominal power. As a consequence, the WTG can operate with the rotational speed in a range of ±25%–30% around the synchronous speed, and itsactive and reactive powers can be controlled independently.

In this paper, an ESS consisting of a supercapacitor bank and a two-quadrant dc/dc converter is connected to the dc link of the DFIG converters. The ESS serves as either a source or a sink of active power and therefore contributes to control the generated active power of the WTG. The value of the capacitance of the supercapacitor bank can be determined by

$$\mathbf{Cess = 2P_nT / V^2_{SC}} \quad \mathbf{(13)}$$

where *C*ess is in farads, *Pn* is the rated power of the DFIG in watts, *V*SC is the rated voltage of the supercapacitor bank in volts, and *T* is the desired time period in seconds that the ESS can supply/store energy at the rated power (*Pn*) of the DFIG. The use of an ESS in each WTG rather than a large single central ESS for the entire wind farm is based on two reasons.

First, this arrangement has a high reliability because the failure of a single ESS unit does not affect the ESS units in other WTGs. Second, the use of an ESS in each WTG can reinforce the dc bus of the DFIG converters during transients, thereby enhancing the low-voltage ride through capability of the WTG [10].

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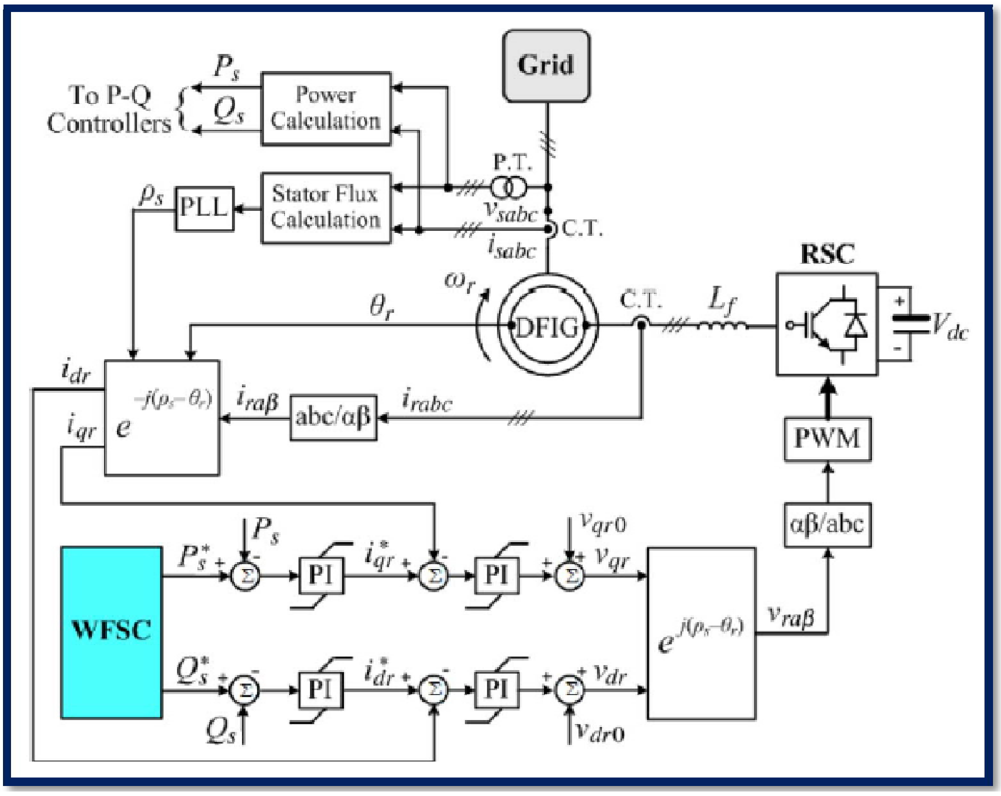

Fig. 3.1. Overall vector control scheme of the RSC

IV.CONTROL OF INDIVIDUAL DFIG WIND TURBINE

The control system of each individual DFIG wind turbine generally consists of two parts: 1) the electrical control of the DFIG and 2) the mechanical control of the wind turbine blade pitch angle and yaw system. Control of the DFIG is achieved by controlling the RSC, the GSC, and the ESS (see Fig. 1). The control objective of the RSC is to regulate the stator-side active power *Ps* and reactive power *Qs* independently. The control objective of the GSC is to maintain the dc-link voltage *V*dc constant and to regulate the reactive power *Qg* that the GSC exchanges with the grid. The control objective of the ESS is to regulate the active power *Pg* that the GSC exchanges with the grid. In this paper, the mechanical control of the wind turbine blade pitch angle is similar to that in [7].

V.SIMULATION & RESULTS

Simulation studies are carried out for a wind farm with 15 DFIG wind turbines (see Fig. 5.1) to verify the effectiveness of the proposed control scheme under various operating conditions.
Each DFIG wind turbine has a 3.6-MW power capacity. The total power capacity of the wind farm is 54 MW. Each DFIG wind turbine is connected to the internal network of the wind farm through a 4.16/34.5-kV voltage step-up transformer. The high-voltage terminals of all transformers in the wind farm are connected by 34.5-kV power cables to form the internal network of the wind farm. The entire wind farm is connected to the utility power grid through a 34.5/138-kV voltage step-up transformer at PCC to supply active and reactive powers of *P* and *Q*, respectively. In this paper, the power grid is represented by an infinite source. The ESS of each WTG is designed to continuously supply/store 20% of the DFIG rated power for approximately 60 s.

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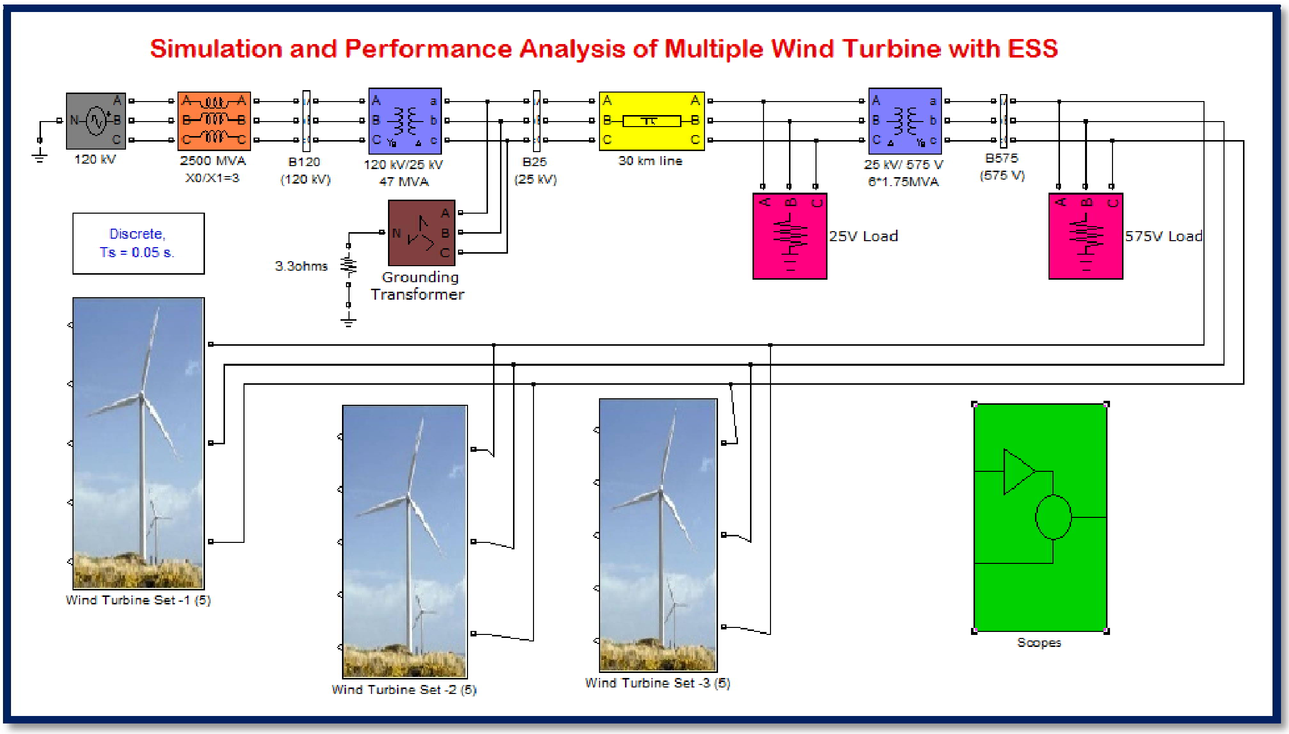

Figure 5.1: Simulink model of DFIG wind turbine with energy storage system

A. CPC During Variable Wind Speed Conditions

Fig. 5.2 shows the wind speed profiles of WTG1 (*vw*1), WTG6 (*vw*6), and WTG11 (*vw*11). The wind speeds across the three WTGs vary in a range of ±3 m/s around their mean value of 12 m/s. The variations of wind speed cause fluctuations of the electrical quantities of the WTGs. If the wind farm is not equipped with any energy storage devices or the proposed CPC scheme, the wind speed variations in the wind farm result in significant fluctuations of the total output active power at the PCC. The wind farm power output deviates significantly from the active power demand or commitment. In future electric power grids where the penetration of wind power is high (e.g., 20%), such active power fluctuations can bring severe problems to grid operation.

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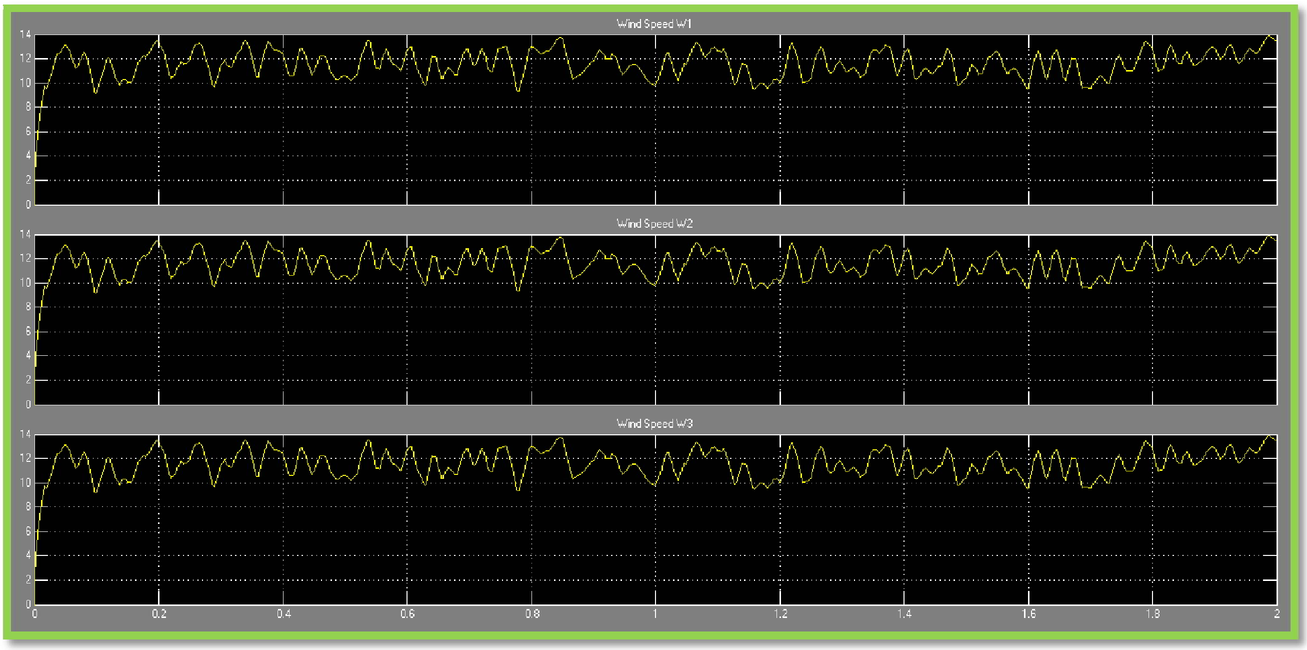

Figure 5.2: Wind Speed of Wind Turbines

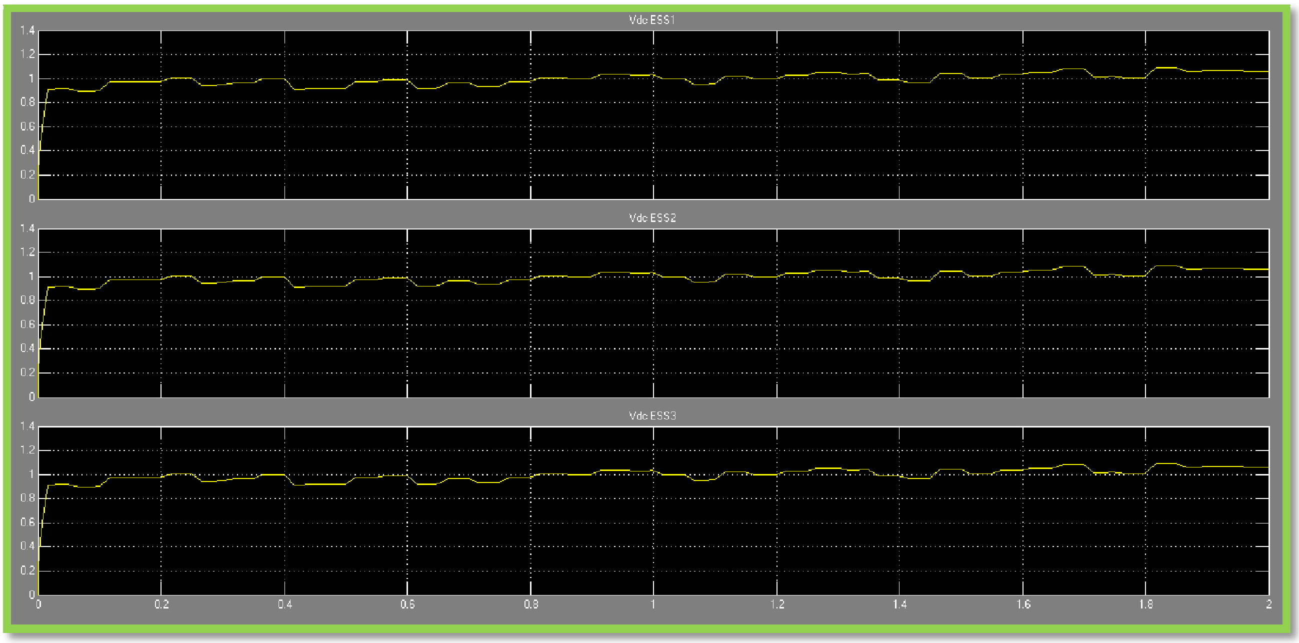

Figure 5.3: Voltage of Energy Storage Systems

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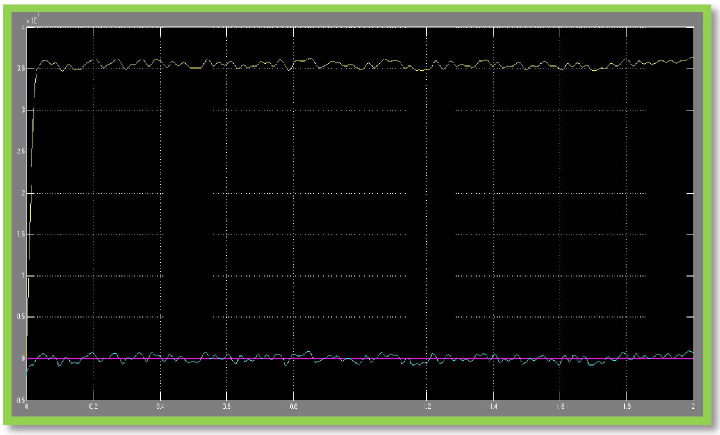

Figure 5.4: Output of active power and power generated by wind turbine W1

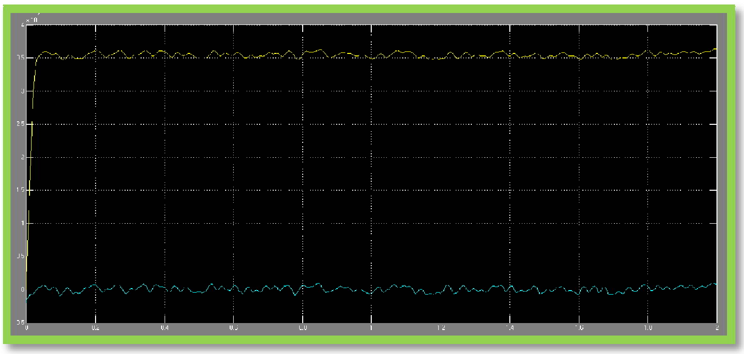

Figure 5.5: Output of active power and power generated by wind turbine W2

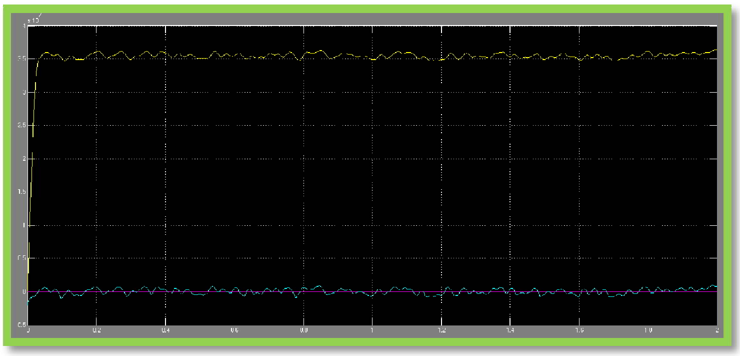

Figure 5.6: Output of active power and power generated by wind turbine W3

VI.CONCLUSION

This paper has proposed a novel two-layer CPC scheme for a wind farm equipped with DFIG wind turbines. Each wind turbine is equipped with a supercapacitor-based ESS, which is connected to the dc link of the DFIG through a two-quadrant dc/dc converter. The ESS serves as either a source or a sink of active power to control the generated active power of the DFIG wind turbine. Each individual DFIG wind turbine and its ESS are controlled by low-layer WTG

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controllers, which are coordinated by a high-layer WFSC to generate constant active power as required by or committed to the grid operator.

Simulation studies have been carried out for a wind farm equipped with 15 DFIG wind turbines to verify the effectiveness of the proposed CPC scheme. Results have shown that the proposed CPC scheme enabled the wind farm to effectively participate in unit commitment and active power and frequency regulations of the grid. The proposed system and control scheme provides a solution to help achieve high levels of penetration of wind power into electric power grids.

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BIOGRAPHY

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