Journal of Engineering and Applied Sciences 11 (9): 2072-2078, 2016
ISSN: 1816-949X

Mathematical Modeling and Simulation of DFIG Wind Turbine

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Abstract: In system to meet power needs, Due to the account Economical and environmental factors, wind energy conversion is progressively gaining interests as a convenient source of renewable energy. A Wind Energy Conversion System (WECS) differs from a conventional the power system. The power output of aconventional power plant can be controlled whereas the power output of a WECS depends on the wind. In this study, by using the MATLAB Software, the power electronic system mathematical model relevant to the wind speed, driving mechanism, power generator and wind power is established and the research of simulation is accomplished which are used for analysis of simulation results. This study introduces the control technology of wind turbine, that mainly about variable pitch control and generator speed control and this study carries out the simulation pitch control system and under-rated and top-rated wind speed variable speed wind power system using the software of MATLAB.

Key words: Double Fed Induction Generator (DFIG), wind energy, wind turbine control system, mathematical modeling, WECS

INTRODUCTION

Electric energy is one of the most important and highly consumed sources of energy. Majority of our daily life applications consume electric power. Due to the increasing population and more industries coming up, the demand for electricity is escalating. To counter such a situation new forms of alternate energy generation techniques have been looked into which could provide clean energy. For a few decades now, the trend of renewable energy for energy generation has been adopted all over the world. The installation of such renewable plants are visible almost everywhere now a days. Due to the global warming issue, change in climate and adoption of green energy concept, most of the countries are deviating from pollution cause sources to environmental friendly sources. The best forms of renewable energy are solar energy, wind energy, tidal energy and wave energy. All of them are clean, available for most of the time in a year and efficient. This study discusses about harvesting energy from wind. Wind energy is one of the fastest growing industries worldwide. It is preferred due to its simplicity of design and many available geographic options for installation, be it in shore or off shore. It does not only work during day time, as does solar energy, thus can generate energy throughout the day and throughout the year. For such visible advantages of wind over other forms of energy, it will continue to grow in the coming years as the demand for energy will exceed the generation rate. The concept of wind power originated in 1970s and matured in 80s years, furthermore the development at big stage was held in 1990s (Naemmance *et al*., 2007). In the beginning, wind energy generation was designed as a basic fixed pitch stall control to full control of blade pitch. The energy conversion principle and aerodynamics of wind turbines are based on systematic analysis of fixed-pitch wind turbines.

Create a system simulation model. Generally, the higher the simulation model finer degree of control but the higher the degree of difficulty. In this study, starting from the application of the principles of object, first analyses and mathematical models of wind turbines and wind turbine model the whole, so the simulation study. Natural wind energy is the source of wind power generation system which is in the process flow, speed and direction is constantly changing with strong randomness and mutation. This article does not consider the wind problem, just change the characteristics of its emphasis describe its randomness and intermittent that its spatial and temporal model consists of the following four components: The basic wind speed wind gusts, gradient wind and noise wind. So the model simulated wind speed (Wang *et al*., 2014):

$$V = V_b + V_r + V_g + V_t$$

Generally, Vail basic wind speed distribution parameters of wind farms can be obtained to determine the

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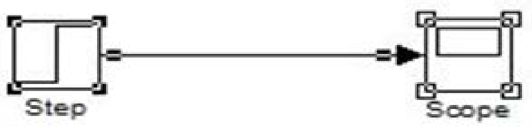

Fig. 1: Diagram of simulation-based wind speed

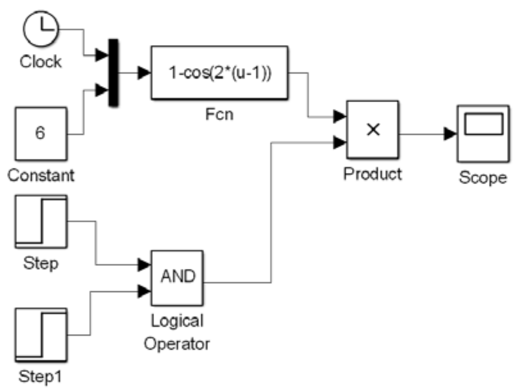

Fig. 2: Diagram of simulation gust

approximate wind and it does not change with time and thus taken as a constant. In this study, the basic wind speed 6 m sec^{-1}. Its simulation (Fig. 1). The gust component is represented as a term and is given:

$$v_g = \begin{cases} 0 & t\langle T_1 \\ v_{wg} & T_1\langle t\langle T_2 \\ 0 & t\rangle T_2 \end{cases}$$

$$v_{wg} = C_2[1-\cos(\pi\frac{t-T_1}{T_2-T_1})]$$

Where

C_2 = The maximum value of the gust component

T1 and T2 = The start and stop times of the gust, respectively

Simulation Fig. 2: The rapid wind speed changes are represented by a ramp function which is given by:

$$v_r = \begin{cases} 0 & t\langle T_3 \\ v_{wr} & T_3\langle t\langle T_4 \\ 0 & t\rangle T_4 \end{cases}$$

$$v_{wr} = C_3(\frac{t-T_3}{T_4-T_3})$$

Where:

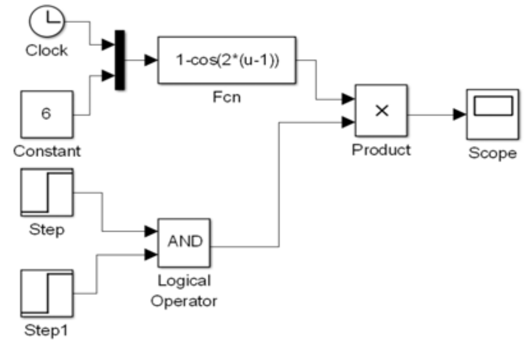

Fig. 3: Diagram gradient wind simulation

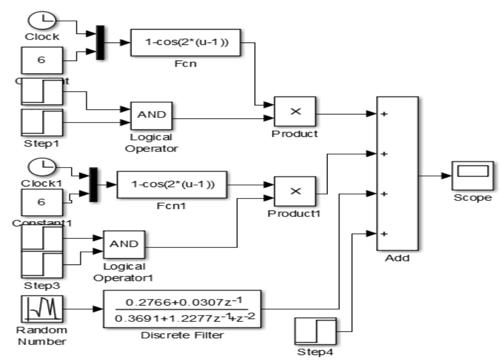

Fig. 4: Diagram natural wind simulation

C_3 = The maximum change in wind speed caused by the ramp

T3 and T4 = The start and stop times of the ramp respectively

Simulation (Fig. 3): The noise component of the wind speed is not modelled, as the large turbine inertia does not respond to these high frequency wind speed variations. The four were part of the characteristics of natural wind simulation in the diagram is shown Fig. 4.

Double-fed wind generator: As shown in Fig. 5, the basic physical structure of doubly-fed wind generators consists of the wind turbine, shaft and gear box, double-fed induction generator, dual PWM converter and its control system (Xu and Cartwright, 2006). Wind turbines function by converting the wind power obtained through vanes into the mechanical torque acting on the hub; the drive shaft and gear box are to transmit the driving function of wind turbines to power generators and improve the rotation speed. The gearbox gear ratio can reach as high as 100. Similar to winding asynchronous motors, double-fed induction generators transform the

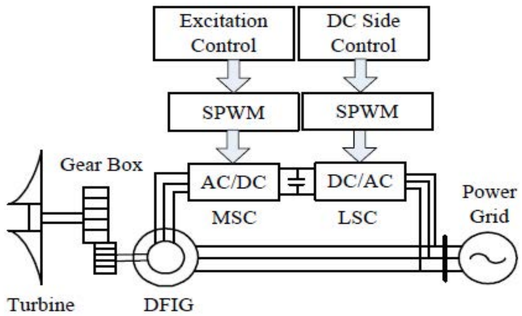

Fig. 5: The block diagram of double-fed wind turbine generators

mechanical energy into electrical energy and guarantee the output of AC voltage with constant frequency; composed of two back-to-back Voltage Source Converters (VSC), the dual PWM converter relies on the common DC capacitor to maintain the DC voltage. On the one hand, the dual PWM converter provides AC excitation voltage for double-fed motors. On the other hand, it provides the power flow path for rotors to rotate between grids and it can operate in four quadrants.

The core control unit of DFIG is the dual PWM converter including the machine-side converter and the grid-side converter. The one directly connected with rotor windings is called the machine-side converter which becomes the grid-side converter by being directly connected with the grid through linking with rotor circuit via the slip ring. The direct-current of two converters obtains direct-current support through the common capacitor. The basic function of the machine-side converter is to provide excitation voltage for double-fed generators and implement decoupling adjustment of active power and reactive power under the strategy of vector control; the major function of the grid-side converter is to maintain capacitor voltage constant under the control of direct-current regulation system and regulate the power factor. Furthermore, these two "back to back" converters constitute the four-quadrant invertible flow system. In other words, active and reactive power flow in both directions can be achieved from the machine side to the grid side. Rotor-side converters produce the three-phase low-frequency AC current at the rotor circuit. The three-phase low-frequency AC current builds a low frequency rotating magnetic field relative to rotors and the rotational speed of the magnetic field can be regulated through dynamic control of the rotor converter. Compared with conventional synchronous generators (the magnetic pole is stationary relative to rotors), double-fed wind generators can operate in a great speed range, which is therefore named variable speed wind generators.

MATERIALS AND METHODS

Mathematica model of double fed wind generators: Due to the generalized Park equation of Doubly Fed Induction Generators (DFIGs) with stator flux (ψ_{ds}, ψ_{qs}) and the rotor current (i_{ds}, i_{qs}) being state variables, the state equation under the d-q peculiarities system is expressed as (Moursi *et al.*, 2008):

$$\begin{cases} \rho\psi_{ds} = \frac{r_s}{l_s}\psi_{ds} + l''r_s i_{dr} + \omega_1\psi_{qs} \\ \rho\psi_{qs} = \frac{r_s}{l_s}\psi_{ds} + l''r_s i_{qr} + \omega_1\psi_{qs} + \mu_{qs} \\ \rho l' i_{dr} = -r_r i_{dr} + \mu_{dr} + \omega_s l' i_{qr} + \omega_s l''\psi_{qs} - l''p\psi_{ds} \\ \rho l' i_{qr} = -r_r i_{qr} + \mu_{qr} + \omega_s l' i_{dr} + \omega_s l''\psi_{ds} - l''p\psi_{qs} \end{cases}$$

$$l' = l_r - \left(l^2_m / l_s\right), l = l_m / l_s$$

Where:

l_S, l_r and l_m = Indicative the stator self-inductance, rotor self-inductance and mutual inductance respectively
r_s and r_r = Indicative the stator resistance and rotor resistance
ω_1 and ω_s = Indicative the synchronous speed and slip
u_{ds} and u_{qs} = The vertical and horizontal component of the excitation voltage
p = The differential operator

In order to achieve the frequency output of the generator output voltage control and active and reactive power of independent regulation, the need to implement vector control of doubly-fed generator, in accordance with the provisions of the preceding positive direction: Generator stator side by convention, a positive current produces a negative flux; rotor side in the positive direction by motor practice, a positive current produces a positive flux.

Vector control strategy: For perform the direct power control on DFIG, the mathematical analysis of DFIG has been created. Since, the Stator and rotor of the DFIG is fed via grid and rotor converters, the required voltage to energize the stator and rotor is provided by separate voltage sources. The equivalent T representation of DFIG is shown Fig. 6 (Hansen *et al.*, 2001; Muljadi and Ellis, 2008).

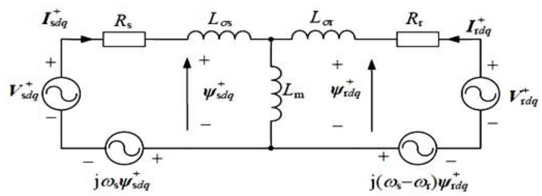

Fig. 6: The equivalent T representation of DFIG

$$U_s = R_S i_S + \rho\psi_s + j\omega_1\psi_s$$

$$U_r = R_r i_r + \rho\psi_r + j\omega_r\psi_r$$

Stator and rotor flux linkage equations are expressed as follows:

$$\psi_s = L_s i_s + L_m i_r$$

$$L_s = L_m + L \rightarrow \text{Stator leakage inductance}$$

$$\psi_r = L_m i_s + L_m i_r$$

$$L_r = L_m + L_{1r} \rightarrow \text{rotor leakage inductance}$$

If the stator flux vector is as follows:

$$\psi_s = L_m i_{ms}$$

Stator and rotor flux then it can be calculated as follows:

$$i_s = \frac{L_m}{L_s}(i_{ms} - i_r)$$

$$\psi_r = \frac{L_m}{L_s} \times i_{ms} + \sigma L_r i_r$$

$$\sigma = \frac{L^2_m}{L_s}$$

As a result of placing the above equations in the equation of the stator voltage and rotor achieved as follows:

$$U_s = R_s i_s + L_m \frac{di_{ms}}{dt} + j\omega\psi_s$$

$$U_r = R_r i_r + \sigma L_m \frac{di_r}{dt} + \frac{L^2_m}{L_s} \times \frac{di_{ms}}{dt} + j\omega_s\psi_r$$

When the system works in steady state voltage and frequency and phase delay U_s so much also remains unchanged and stable ψ_s also in this case, the above equation can also be reduced as follows:

$$U_s = R_s i_s + j\omega_1\psi_s$$

$$U_r = R_r i_r + \sigma L_m \frac{di_r}{dt} + j\omega\psi_s$$

If we ignore the losses of the stator in a permanent state, the generator output voltage can be expressed as follows:

$$U_s = j\omega_1\psi_s$$

And if the reference phase vectors q-d with induction generator output voltages of both malnutrition q-axis voltage component generator is zero and thus the reference voltage generator terminals q-d can be stated as follows:

$$U_{sd} = -\omega_1\psi_{sq} = -\omega_1(L_s i_{sq} + L_m i_{rq})$$

$$U_{sq} = \omega_1\psi_{sd} = \omega_1(L_s i_{sd} + L_m i_{rd})$$

According to the equation above the rotor flux is achieved as follows:

$$\psi_r = \sigma L_r i_{rd} + j\left(\frac{-L_m}{\omega_1 L_s} \times U_s + \sigma L_r i_{rq}\right)$$

And placing the above equation rotor voltage equation is as follows:

$$U_r = R_r i_{rd} + \sigma L_r \frac{di_{rd}}{dt} + \frac{\omega_s L_m}{\omega_1 L_s} * u_s - \omega_s \sigma L_r i_{rq} +$$
$$j(R_r i_{rq} + \sigma L_r \frac{di_{rq}}{dt} + \omega_s \sigma L_r i_{rq})$$

The above equation can be as basic equations for the inner loop control flow generator in a permanent state of network connectivity or times be considered.

Control model of machine side converter: When the voltage in the utility grid changes suddenly due to abrupt

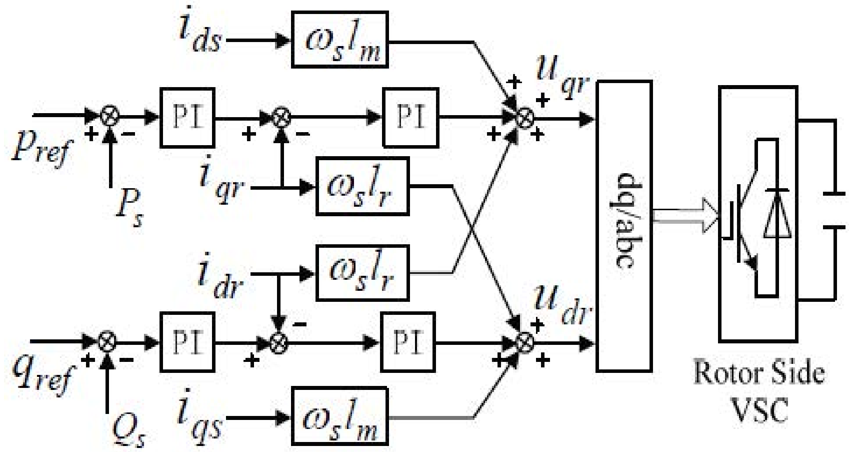

Fig. 7: The control model of rotor-side converters

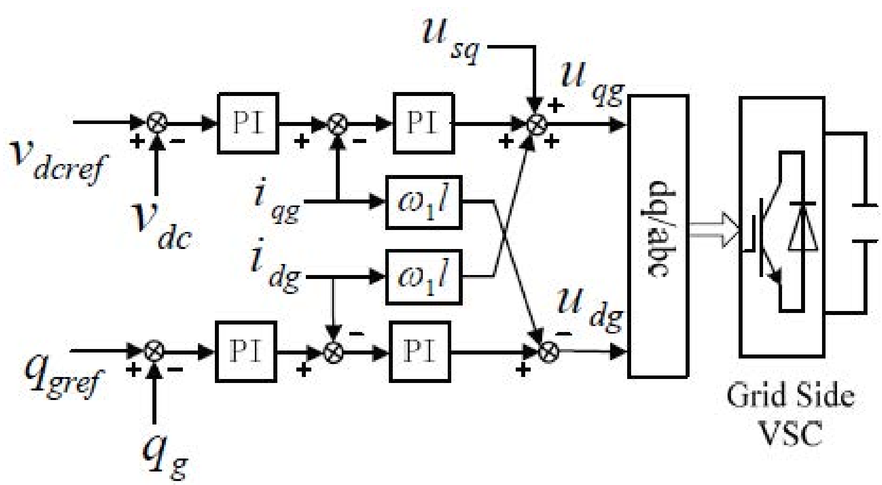

Fig. 8: The control model of grid-side converters

load variations and sudden wind speed changes, it makes an effect on the machine, as a result the system voltages accessible across stator as well as rotor variations. Because the converters are connected back-to-back the same effect is also considered across these two converters and on the dc link capacitor as well. The indispensable control action is adopted to maintain the dc link voltage constant (Lopez *et al*., 2007, 2009). The control scheme utilizes current control loops for i_d and $i_q$with the $i_d$demand being derived from the dc link voltage error through a standard PI controller. The i_q demand determines the displacement factor on the grid side of the choke. The active power and reactive power is controlled independently using d-q component of the current governed by $P = 3/2(v_d i_d + v_q i_q)$ and $Q = 3/2(v_q i_d - v_d i_q)$.

The control block diagram is shown in Fig 7. Due to the dq/abc coordinate transformation, the q-axis of the d-q coordinate system can be taken as the stator voltage vector or stator flux vector or other vectors. If the stator flux vector is considered as the q-axis, we require determine the orientation of the stator flux that is obtained according to specific algorithms by measuring the stator current and rotor current. Doubly fed generators use different control strategies at low wind speed and high wind speed. But we purely discuss the given control mode under high wind speed in that the reference value under low wind speed is not fixed.

Control model of grid side converter: In accordance with to rotor-side converters, grid-side converters also achieve the active and reactive power decoupling control through the vector control strategy. Rotor side converter control model is shown in Fig. 8. The reactive power is exchanged among RSC and the grid, via the generator. In the exchange process the generator alluring reactive power to supply its mutual and leakage inductances (Mishra *et al*., 2009). The additional of reactive power is sent to the grid or to the RSC. In Fig. 8 $V_{dc_{ref}}$ and $q_{g_{ref}}$ are the reference values of DC-side voltage and generator reactive power respectively; V_{dc} and q_g are the DC-side voltage and generator reactive power respectively; i_{d_g} and represent the d-axis component and the q-axis component of the grid-side converter current respectively; u_{s_1} is the grid side voltage; l is the choke inductor; u_{d_g} and u_{q_g} indicative the d-axis component and the q-axis component of the grid-side converter voltage; ω1 is the grid-side frequency. Through the dq/abc Transformation u_{d_g} and u_{q_g} indicative the control signal under the abc coordinate and control the output voltage of the grid-side converter to achieve the regulation of capacitor voltage and power factor.

RESULTS AND DISCUSSION

Simulation of double fed generator system: Using Matlab/Simulink to build the entire VSCF doubly fed wind power generation system simulation model, as shown in Fig. 9. The wind turbine simulation module which uses Matlab 7. 5.0 inherent in wind turbine module (Simulink/ sim power systems/application libraries/distributed resources/wind turbine) (Fig. 10). Doubly-fed generator parameters are set as follows: Rs = 0.0076 Ω rr = 0.005 Ω xs = 0.0056 Ω xr = 0.0048 Ω np = 2 f = 60 hz v = 10 $msec^{-1}$ p = 1500 kw. Through simulated wind power system voltage and current waveforms at bus 25 kW as follows: get doubly-fed wind power generator and its voltage waveform issued as follows (Fig. 11): through simulation waveform analysis can be seen in the

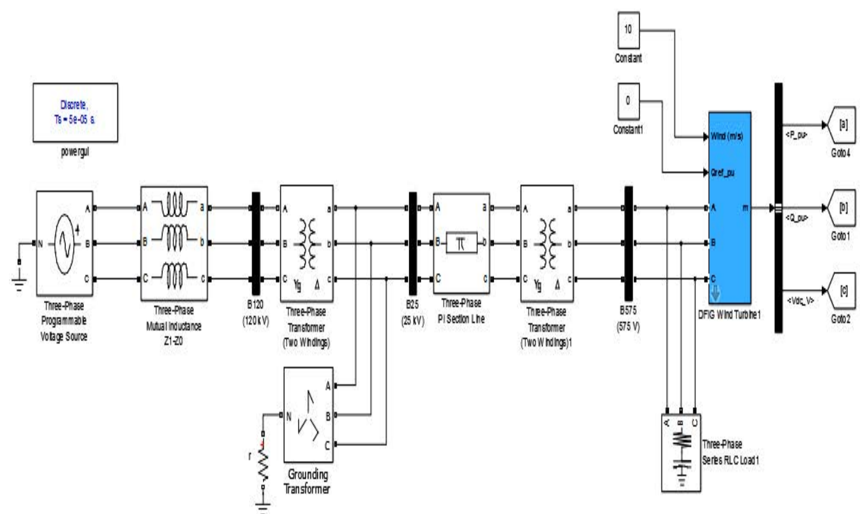

Fig. 9: Simulation model generator system from malnutrition

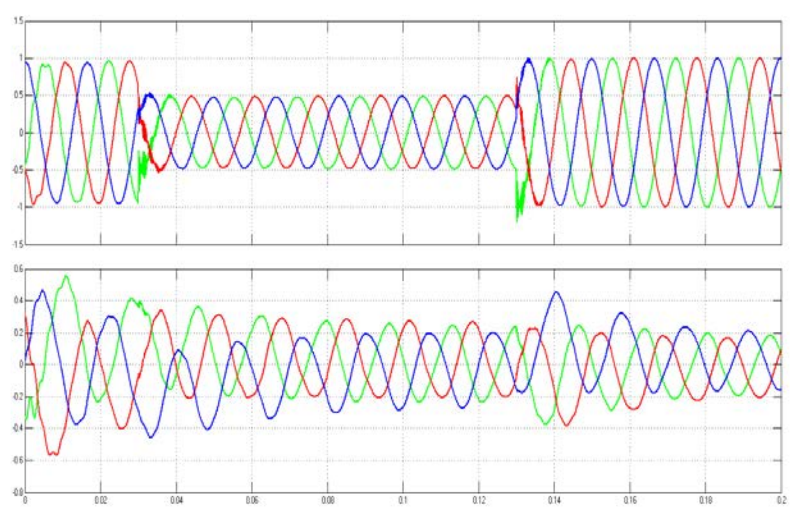

Fig. 10: Voltage and current waveforms

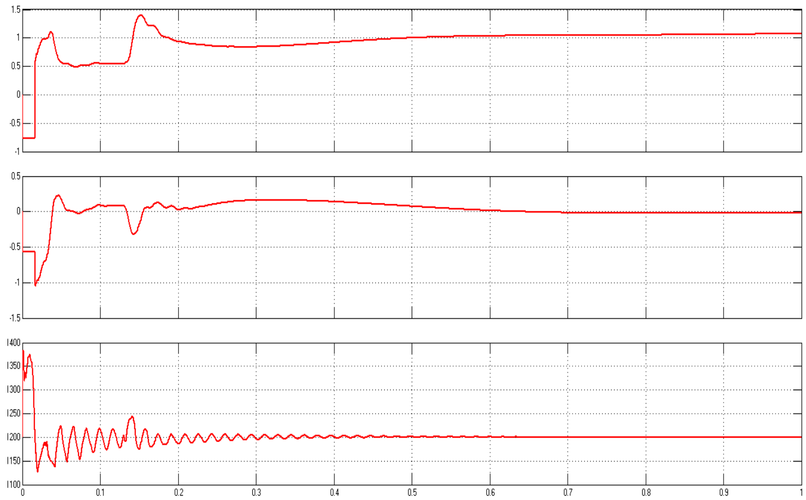

Fig. 11: Voltage waveform and power

distribution of wind power and its voltage distribution systems, the study of the stability of the system in order to more easily understand the operation of the wind power generation system.

CONCLUSION

Wind power is a clean and renewable energy and its technology has been developed more mature, compared with other renewable energy sources. In the foreign countries, the history of operation and studying of Wind power has been on for decades. With the popularity of wind power generation in these countries, the simulation of wind power generation system will also play a huge role in the design and operation of wind farms and wind power management. In order to improve the doubly-fed wind generator pull into the grid control technology, the double-fed wind generous can be controlled by using the advanced control algorithms combine with vector control, thus to find the optimal control scheme. In short, the double-fed wind power generation technology is in its continuous development and progress, there are many theoretical approaches and practical techniques remain to be studied, which makes doubly-fed wind power technology continue to improve.

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