SIMULATION STUDY ON PERMANENT MAGNET WIND POWER GENERATION SYSTEM BASED ON PSIM

Nan Li[1], Bing YU[2], Lei Liu[1], Bing Kong[2]

E.E., State Grid Chengdu Electric Power Supply Company, Chengdu, Sichuan, China [1]

PG Student, School of Electrical Engineering and Information, Southwest Petroleum University, Chengdu, Sichuan, China [2]

ABSTRACT: Through systematically analyzing the mathematical theory knowledge of the small and medium-sized direct-drive permanent magnet wind power system, this paper has designed a rated power of 3kW wind power system under the environment of PSIM9.0 software. The wind power system model has been built, the back-to-back double-PWM control circuit has been designed and the simulation analysis has been completed. In the circumstance of wind speed changes, the simulation results show that the output power of the generator side is stable and the DC voltage of the inverter side is constant, which suggests the correct control strategy, the favorable system stability, and the achieved design goal. The work already done in this article provides a good platform and infrastructure for systematically analyzing the small and medium-sized wind power system.

Keywords: PSIM; wind power system; PMSG; full power converter; simulation analysis.

I.INTRODUCTION

With the increasing depletion of fossil energy, and the continuing deterioration of global environment, the wind power generation, as one kind of new energy power generations, has been paid further attention by the governments and researchers with its unique advantages. Recently, along with the small and medium-sized independent power generation achieving strong support by the relevant national policies, small and medium-sized wind turbines have been vigorously promoted and applied [1]. It is mainly used in remote areas where there is wind but no electricity and it is used as the self-provided power plant by some enterprises, such as remote regions, border posts, lonely islands, large-scale agriculture, animal husbandry, fisheries and oil fields, etc. Therefore, the research on small and medium-sized wind turbine system has great significance. The direct-drive permanent magnet wind turbine system is a research hotspot in recent years, and the permanent magnet synchronous generator (PMSG) has been widely used with its good control precision, high efficiency, low maintenance and many other advantages.

Study in this paper is based on PSIM9.0 simulation software. PSIM9.0 is a dedicated simulation software for power electronics and motor control study, it has the main features of user interface simple, learning and understanding easy, operation convenient, simulation fast, simulation waveforms clear and intuitive, etc [2]. Compared to the previous version, PSIM9.0 has newly added the solar cell model and wind turbine module which are related to the new energy power generation, thereby providing a superior platform for wind power generation system design and analysis in this article.

Utilizing MATLAB/Simulink and PSCAD/EMTDC respectively, literature [3] and [4] have completed the WECS related research work. These two softwares are so powerful that they can realize the complex simulation analysis, however, they launch slowly, have longer simulation time and more complex component modules and control loops while compared with PSIM. Although the simulation software in literature [5] has perfect function, it is not universal and it is not suitable for widespread utilization. Literature [6] and [7] have established the permanent magnet synchronous motor (PMSM) control system simulation model and Maximum Power Point Tracking (MPPT) control system model of WECS respectively, but they did not establish complete WECS models and do simulation analysis. Using PSIM software which can be used to build the simulation system model quickly and intuitively, this paper has set

up a system model and finished the small and medium-sized wind power system simulation, and the generator speed and grid voltage being controlled accurately has been realized, which provides new ideas for WECS researches.

II. PERMANENT MAGNET WIND POWER GENERATION SYSTEM OVERVIEW

Wind power generation system consists of wind turbine, PMSG, converter and control system, the basic structure is shown in Fig.1. Differ from traditional asynchronous wind power generator system, PMSG system eliminates the need for heavy overdrive gearbox, which improves the reliability of power plant operation and the efficiency of wind energy utilization. Moreover, PMSG system absorbing reactive power barely from the power grid and full-power converter achieving low voltage ride through (LVRT) provide a reliable guarantee for the increasingly stringent wind power integration demands. In short, the direct-drive permanent magnet wind power generation system has the following salient features [8]: 1) Light weight and small size generator; 2) Small electromagnetic interference and good electromagnetic compatibility; 3) Simple structure, high reliability and long service life; 4) High efficiency and significant energy saving effect; 5)Good social adaptability under harsh environments; 6)Good voltage waveform quality and adaptable to a variety of load changing circumstances.
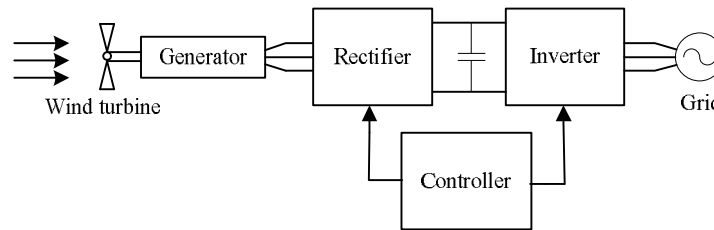

Fig.1 Permanent magnet wind power generation system block diagram

III. WIDN POWER GENERATION SYSTEM MATHEMATIC MODEL

3.1 Power Characteristics of Wind Turbine

Wind turbine is a key part of the whole wind energy conversion system, its main function is to capture wind energy and converter it to the mechanical kinetic energy effectively. So, wind turbine not only affects the output efficiency and stability of the entire wind power generation system, but also directly determines the system operation status. According to fluid mechanics knowledge, the kinetic energy produced by airflow sweeping wind turbine is the input power of the wind turbine, which can be expressed as follows.

$$E = \frac{1}{2}mv^2 = \frac{1}{2}\rho Sv^3 \ (1)$$

Where, m is the air quality, S is the swept area of blades, v is the wind speed, ρ is the air density.
According to Betz limit theory [9], the maximum power that the wind turbine can export theoretically is shown in the following equation (2).

$$P_{max} = EC_{p\,max} = \frac{1}{2}\rho v^3 SC_{p\,max} \ (2)$$

Where, $C_{p\,max}$ is equal to 0.593, however, in the actual operation, it is almost impossible to achieve the value and is generally taken to be 0.4. The output torque formula of wind turbine can be expressed as follows.

$$T_m = \frac{P}{\omega} = \frac{1}{2}\rho v^3 S \, C_p / \omega \ (3)$$

Where, P is the output power, C_p is the power conversion factor and ω is the angular velocity of wind turbine blade rotation.

3.2 Permanent Magnet Synchronous Generator Model

During the operation process of PMSG, the rotor and stator keep a relative movement state, and there are mutual influences between windings and permanent magnet and windings. Coupled with the nonlinear factors such as

magnetic circuit saturation, the electromagnetic relation is very complicated. Hence, it is difficult to establish accurate mathematical model of PMSG. Therefore, in order to facilitate analysis, the following assumptions are made: 1) Y-connected stator windings; 2)Sinusoidal back-EMF, no considering the effect of space harmonic and magnetic circuit saturation; 3)Excluding eddy current and hysteresis losses; 4)No dynamic response process of excitation current.

In the d-q axis rotation coordinate system，the voltage and electromagnetic torque mathematical relationships of PMSG are expressed as follows [10].

$$\begin{cases} V_d = -\omega_c \psi_q + (R_s + pL_d)i_d \\ V_q = \omega_c \psi_d + (R_s + pL_q)i_q \end{cases} \quad (4)$$

$$\begin{cases} \psi_d = L_d i_d + \psi_f \\ \psi_q = L_q i_q \end{cases} \quad (5)$$

$$T_e = \frac{3}{2} n_p [\psi_f i_q + (L_d - L_q)i_q i_d] \quad (6)$$

Where, ψ_d and ψ_q are the stator flux linkages corresponding to d-axis and q-axis respectively, L_d and L_q are the two-phase stator windings self-inductances corresponding to d-axis and q-axis, R_s is the stator resistance, i_d and i_q are the armature currents for d-axis and q-axis respectively, ω_c is the rotor rotating angular speed, p is the differential operator symbol, n_q is the motor pole pairs, ψ_f is the permanent magnet flux linkage and it is a constant.

IV. CONTROL STRATEGIES AND MODELING

Back-to-back double PWM full power converter consists of generator side converter, DC link and grid side inverter. The generator side converter receives active power firstly, then this part of active power is sent to the grid side converter through the DC link and finally to the grid. Due to the speed of wind and generator changes unceasingly, the output of generator voltage and frequency varies, so, in order to achieve grid voltage and frequency requirements, control method of dual PWM converter is the key.

4.1 Control Strategy and Simulation Model of Generator Side

The purpose of generator side converter control while wind speed changes, is to regulate the generator torque and rotating speed, and achieve maximum power tracking control. In the rotating coordinates, as formula (6) shows, when $L_d = L_q$, torque is only related to q-axis current, therefore, the torque control is equal to current control. In short, the control strategy of generator side is double closed loop control which puts the current control as inner loop control and the speed control as the outer loop control.

During the control process, the torque and rotating speed depends on the size of the space vector current, through controlling i_d and i_q, the actual i_d and i_q track the control signal i_d^* and i_q^*, then the control objective is achieved. The simulation model under PSIM simulation environment is shown in Fig.2.
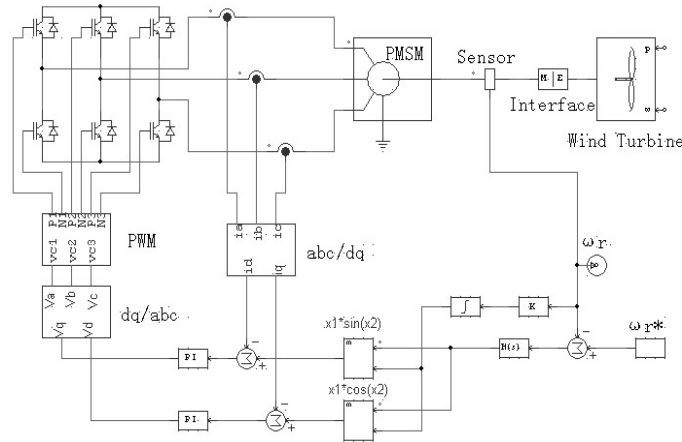
Fig.2 Generator side rectifier control model

4.2 Control Strategy and Simulation Model of Grid Side

The grid-side three-phase voltage converter in fact is the rectifier which works in inverter state, controlling the inverter makes DC bus voltage stability and grid-side unit power factor operation. Traditional small and medium-sized wind power system is controlled by single current control method, aiming at the shortcomings of the method, this paper adopts double closed-loop controlled voltage oriented vector control method [11]. Voltage oriented vector control is divided into indirect control method and direct control method, this paper adopts the latter which has a better dynamic performance, including closed-loop current control, quick current response and good robustness [12-13]. In the control process, the outer loop voltage signal is affected by the given DC voltage signal V_{dc}^* and the feedback DC voltage signal V_{dc}, while the inner loop current signal is controlled by the coordinate transformed current on the grid side. The simulation model built utilizing PSIM software is shown in Fig.3.
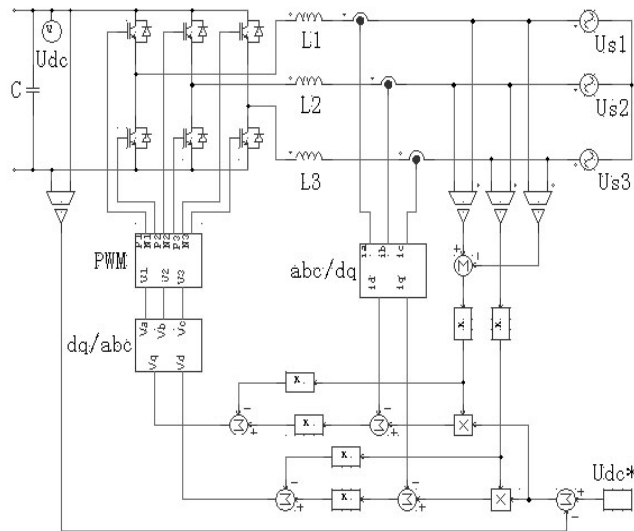

Fig.3 Grid-side inverter control system model

V. SIMULATION RESULTS ANALYSIS

In order to verify the feasibility of the small and medium-sized permanent magnet wind power system, a rated power of 3kW system has been designed, the main parameters of this system is shown in Tab.1. The simulation system model is built utilizing PSIM9.0 software, and the simulation time is set to be 0.5s. When wind speed mutates, in order to verify the system characteristics of maintaining stable operation, it is set from the rated wind speed of 12m/s to 9m/s, the waveform is shown in Fig.4. At this point, the actual change of generator speed and electromagnetic torque is shown in Fig.5. Fig.6 expresses the output power waveform when the wind speed changes, while Fig.7 shows the DC voltage waveform. Fig.8 and Fig.9 indicate the output line-voltage value and the three-phase current value respectively, while Fig.10 illustrates the grid reference voltage.

Tab. 1 Parameter List of Wind Energy System

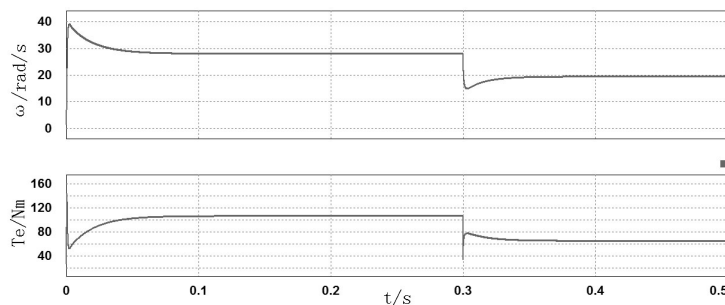| Items	Parameter Values
Air density	$1.2kg/m^3$
Blade radius	2m
Rated wind speed	12m/s
Wind turbine power rating	3kW
Phase voltage	180V
Grid frequency	50Hz
Converter switching frequency	10kHZ
DC bus voltage	400V
DC bus capacitance value	1.9mF
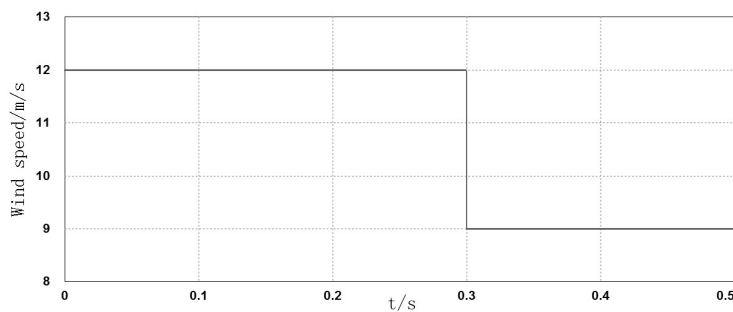
Fig.4 Step Change of Wind Speed

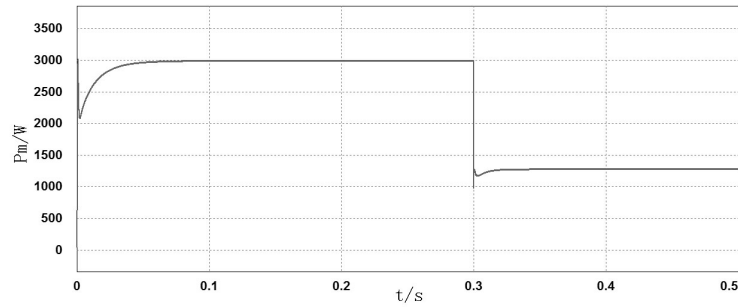Fig.5 Generator Speed and Torque Wave Changes

Fig.6 Generator Output Active Power
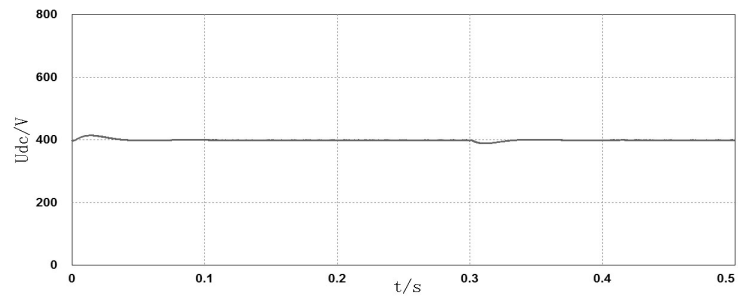
Fig.7 DC Voltage Waveform
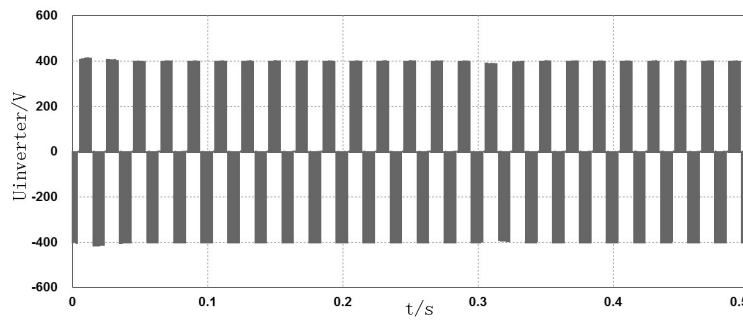
Fig.8 Inverter Output Voltage before the Filter
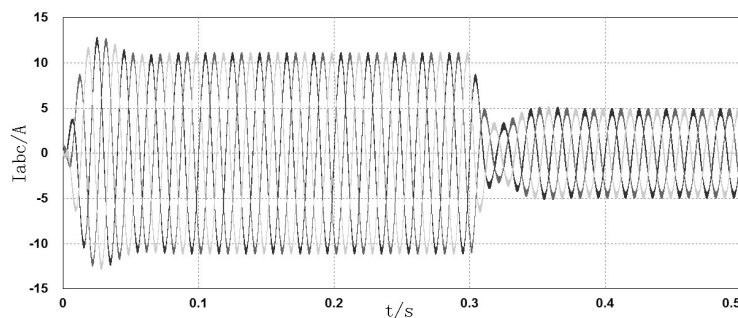
Fig.9 Output Current Waveform
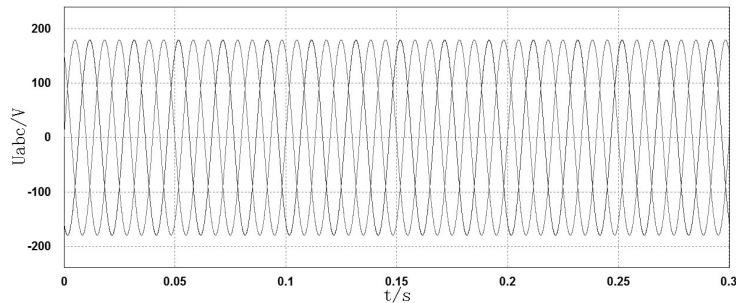
Fig.10 Inverter Output Voltage Reference Value

The pitch angle transformation is not considered in this paper, and the system is operated under or below rated wind speed. Referring to Fig.5, when the wind speed decreases, the generator speed and the electromagnetic torque decreases accordingly, the response speed is very fast for the signal keeps stability after tiny fluctuations. Especially, from Fig.6, the output power signal keeps steady after wind speed changes, which fully meets the requirements of the control system. The grid side DC voltage is a critical parameter which determines whether WECS can incorporate into the power grid or not. In Fig.6, the DC voltage signal transits smooth and recovers quickly and it won't cause big impact and interference to power grid, which satisfies the power grid requirements. The inverter output voltage and current signals in Fig.8 and Fig.9 are good for there are almost no harmonics. In a word, the simulation result indicates that the simulation effect under PSIM environment is good and the output parameters are very standard. At the same time, it demonstrates the system is reasonable and satisfies the design requirements.

VI.CONCLUSIONS

The simulation model of small and medium-sized permanent magnet wind power generation system has been designed based on PSIM9.0, each module parameters has been calculated accurately. The final simulation results are in conformity with the theoretical calculation values, showing that the model design of the small and medium-sized permanent magnet power generation system is reasonable. In PSIM software environment, the system model is clear and intuitive, the control circuit is simple, the simulation waveform is easy analytical, which provides the experimental and investigative basis for small and medium-sized wind power generation.

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BIOGRAPHY

Li Nan is an electrical engineer in the State Grid Chengdu Electric Power Supply Company, Sichuan, China. He obtained his Master degree of Electrical Engineering from the University of Electronic Science and Technology of China (UESTC) in 2011.

Yu Bing is a postgraduate student in South West Petroleum University, Sichuan, China. His research areas of interest include Study of Wind Power Generation System Control and Simulation, Offshore Wind Power Micro-grid Voltage and Frequency Control.

Liu Lei is an assistant engineer in the State Grid Chengdu Electric Power Supply Company, Sichuan, China. He obtained his bachelor degree of administration from North China Electric Power University (NCEPU) in 2008.