Study on doubly closed loop control strategy and simulation analyzing of pmsg wind turbine with back to back converter

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Abstract. The generation technology of wind turbine connected to grid is a hot research in renewable energy application field. Based on doubly closed loop control strategy for the converter, the paper designed the mathematical model and research the attributes of PMSG wind power generation system, adopted double-loop control strategy for generator and grid converter, which is the corresponding main basis to build the entire simulation modelling step by step with Simulink, to control the active and reactive power effectively. Moreover, current dynamic response is fast apparently and the system has capacity to recover from a disturbance. The feasibility and performance of this model had been verified by the Matlab/Simulink, shown the strength and robustness of PMSG system from a disturbance circumstance.

1. Introduction
Nowadays, facing to the increasingly serious energy crisis and the further deterioration of supply-demand, optimize the energy structure and develop the clean and environmentally friendly renewable energy is becoming imminent[1]. Compared to the CSCF (constant speed constant frequency) wind turbine generator, the VSCF (variable speed constant frequency) could achieve higher utilization of wind power, which has been occupying the manufacturing industries and markets of wind power generation gradually[2]. Wherein, DFIG (Doubly-Fed Induction Generator) and PMSG (Permanent Magnet Synchronous Generator) are adopted widely by researchers as the typical VSCF. Owing to the irreplaceable need of gearbox, worse LVRT (Low Voltage Running Through) ability and could not be decoupled to control the converter independently without rotor position sensor, the PMSG would be considered to establish the framework of simulation modeling eventually[3, 4].

The core component of whole modeling is a pair of back to back converter, which equipped with the fundamental double-loop control strategy. To ensure the voltage on DC bus at a stable value and make the output power of stator reach the decoupled level totally, the control strategy should be distinguished into the generator side as well as the grid side. This control strategy is based on the VOC (vector oriented control) method, which would decouple the AC side current into active and reactive current component through the rotated coordinate transformation, thereby could generate the inner current loop and outer DC voltage loop[5]. The double-loop control strategy could enhance the precision and accuracy of control and the ability to inhibit the load disturbance due to add the inner current loop using the characteristics for fast response of current[6].
2. The mathematical model of PMSG wind power generation system

The typical framework of PMSG wind power generation system consists of a wind turbine, a PMSG, a pair of back to back converter and the grid. In theory, the value of wind turbine could transform wind power into the electrical power correspond the formula (the Betz Theorem). And for the variable speed wind turbine, there is a relation between angular velocity of wind turbine and wind speed in Equation (1):

$$\lambda = \frac{R \omega}{\nu}$$  \hspace{1cm} (1)

where $\lambda$ is the tip ratio. The variable speed wind turbine can keep operating in the most efficient situation (the $C_p$ reaches the maximum) through regulating the $\lambda$ at different wind speed, which could achieve the maximum power point tracking (MPPT) \cite{7}. The primary designed principle is according to the Newton’s second law as follows:

$$T_m - T_e = H \frac{d\omega_m}{dt}$$  \hspace{1cm} (2)

where $T_m$ is the mechanical torque, $T_e$ is the electromagnetic torque, $\omega_m$ is the angular velocity of generator and $H$ is the rotated inertia.

Due to the power is equal to torque multiplies angular velocity and the $\theta$ is the differential coefficient of angular velocity on the basis of foundations of physics, the mathematical model of PMSG would be designed as Equation (3), which is equivalent to a DC generator could be controlled independently, where the $\Phi$ is the flux regard as a constant at here.

$$\begin{cases} 
  u = E \sin(\omega t + \theta) \\
  E = k\Phi \omega_m 
\end{cases}$$  \hspace{1cm} (3)

3. The control strategy of converter

The control design of the grid side converter is to ensure the power from generator side could be controlled, which makes the DC-link and AC voltage constant. Hence, establish double closed loop according to the corresponding objectives. The outer voltage loop is planned to control the DC-link and AC voltage to achieve and keep the demanded value, while the inner current loop would regulate the power delivered.

It is necessary to mention that proportion and integration parameter of current loop would be about five times greater than the voltage loop, so the response speed of inner loop will be faster than the outer loop, which means the reference value of stator current on the direct axis could be decided. The control structure diagram of grid side converter had been showed in Figure 1 (a). Compare with the grid side converter, the main objective of the generator side is to totally decouple the power from the wind turbine transformed and could control it independently. Besides the outer voltage loop combined with inner current loop as well, the maximum power point tracking decided the reference value of stator current on the direct axis. The control structure diagram of generator side converter had been showed in Figure 1 (b).
4. Simulation of PMSG wind power generation system

4.1. Design of modeling with Simulink

The sketch of the whole modeling simulation is shown as Figure 2. A wind turbine block connected to a pair of back-back converters which the state would be controlled by two controllers at the bottom of this diagram. For both of generator and grid side controllers, there are phase locked loop (PLL) and DQ transformation to achieve the control objectives apart from the double closed loop\[^8\]. Besides the phase reactance and line impedance existing in the conventional circuit as well as some measurement blocks used for the AC or DC voltage and current, the circuit also included the 3-phase circuit breaker, which could causes the disturbance or fault depending on the value of resistance in operating process and the auxiliary circuit could help system remain steady state when the disturbance appears at AC side. Set 3MW for the rated capacity of wind turbine and the ratio of transformer is 690/11000 (V), additionally, the phase reactance had been decided to 0.1587 Ω and inductance would be 0.10104mH at the rated frequency 50Hz in the case of considering 20% only. The sampling adopts the discrete method and the period is 2μs.

The total built process of modeling would be divided into four steps. The initial modeling consists of a DC voltage source (battery), single converter with controller, a transformer and an AC voltage source network. Then replace the DC voltage source with a large capacitor which is set 50mF and determine the reference voltage on the capacitor is 1300V. In the next step, copy the VSC and its controller except the voltage loop and combine with another AC voltage source, which has been put on one side of circuit connecting the capacitor. Finally, replace the AC voltage source network using the wind turbine block at the input side, which is the final structure of simulation modeling like the Figure 2.

4.2. Analysis of simulation results

Try to run this modeling under the circumstances that set a step signal for wind speed which the initial magnitude is 8m/s and final magnitude is 10m/s at 0.6ms, moreover, according to the short circuit
ratio, set $10\,\Omega$ as the magnitude of single phase resistance in three phase circuit breaker, which would turn on at 1.0ms and turn off at 1.1ms. The outcomes are shown in Figure 3 and Figure 4.

![Figure 3. Waveforms of DC-link voltage, AC voltage, $i_d$ and $i_q$.](image)

![Figure 4. Waveforms of electromagnetic power angular velocity and mechanical torque.](image)

Basically, the direct and quadrate current on the stator would track required value immediately, which means that it has good dynamic response attribute. And the DC-link voltage could also track and remain the required value, which means the output power could be controlled successfully. In whole simulation process, initially, because the wind speed is not large enough, the input power could not provide the required DC-link voltage before 0.6ms. Furthermore, it is obvious to see that the DC-link and AC voltage has returned to the required value after 1.0ms, which means the system is so strong that could recover from a disturbance. Besides, the angular velocity is large at beginning, which causes the tip ratio is large too, so the power coefficient would be extracted on the right side of the maximum point and get close it gradually, which could increase the power that wind turbine transformed and the mechanical torque, while the electromagnetic power would show the declining tendency. However, when the wind speed increases, the power coefficient would start to get away from the maximum point. Hence, all parameters would present the opposite tendency compared with the previous condition absolutely.

5. Conclusion
For the PMSG wind power generation system, this paper purposed and designed a double closed loop control strategy on the basis of PWM technology with converter, which could achieve the objective to control the output power from wind turbine. When a disturbance had been appearing from outer environment, designed system could be able to recover to normal operating situation. At the same time, the dynamic response speed had been still fast. The entire modeling system had been ensured that it could be adopted in laboratory research after simulation with Matlab. Finally, it is necessary to prove that this system could recover from a more serious disturbance or a fault operating circumstance, which is the main shortage that needs to be completed in the future plan.

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