An Improved Scheme of Power Quality in Wind Generation System Using Novel Nonlinear PI Controller

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Abstract. This paper is based on the research of low wind speed area, which is velocity alters rapidly and the wind power concentration is lower. Not only the maximum power point tracking (MPPT) strategy for Wind Generation System would be even more demanding, but also the efficiency of converter in generator sider and gird side by voltage space vector PWM (SVPWM) in field oriented control would be even more achieving. The reaction of controller is the key of control scheme. The wind power system in low wind speed area needs more smoothing and short time oscillation. A new type of nonlinear PI controller has devoted to the enhancement of wind generation system adoption in low wind speed area. The result has presented the comparison between tradition controller and novel controller via Matlab/Simulink.

Introduction

As the development of wind farm, the rich of wind energy resource location is less and less. Low wind speed area is becoming the major areas for future development. We are committed to high efficient and rapid reaction for complex wind resource in low wind speed area. The suitable control scheme of wind power generation system demands more and more. No matter what doubly fed induction generator (DFIG) and permanent magnet synchronous generator (PMSG), in low wind speed area emphasize specially on the great need for blade and electricity units of wind generation system[1].

This paper base on the capacity of 2MW PMSG low-wind turbine. The grid-connected control strategy is AC-DC-AC back to back PWM converter. The part of turbine is help wind turbine to absorb the maximum energy from wind by keeping track of optimal tip speed ratio. Electricity units of enhancement is need field oriented control scheme to use space vector PWM more efficient[2]. Conventional PI has been widely used in various control systems. Increasingly stringent requirements for power quality limits Conventional PI controller in complex environment. In order to continuously improve wind generation performance, a novel nonlinear PI controller is introduced for control scheme research. The wind generation system of simulation study results based MATLAB/Simulink, And experiment results has verified the nonlinear controller’s good performance and smoother output.

Wind Turbine Generation System Modeling

Wind Turbine Model

The Wind turbine of output $P_m$, which capture from wind is expressed as:

$$P_m = 0.5 \rho A v^3 C_p(\lambda, \beta)$$

In the formula shows, $\rho$ is air density, $A$ is the wind turbine capture area, $v$ is wind speed, $C_p$ is the energy coefficient, $\beta$ is the pitch angle, $\lambda$ is tip speed ratio which defined as:

$$\lambda = \frac{R \omega_m}{v}$$
$R$ is the radius of turbine. The direct drive wind turbine is a direct drive system, $\omega_m$ is the angular speed velocity of the rotor which is equal to turbine $\omega_w$.

The $P_m$ and $\omega_m$ can get the aerodynamic torque $T_m$, which relationship is defined as:

$$T_m = \frac{P_m}{\omega_m}$$  \hspace{1cm} (3)

The tip speed ratio $\lambda_i$ and the pitch angle $\beta$ have affected the characteristics of $C_p$, which is shown as follow:

$$C_p(\lambda, \beta) = 0.22\left(\frac{116}{\lambda_i} - 0.4\beta - 5\right)\exp\left(-\frac{12.5}{\lambda_i}\right)$$  \hspace{1cm} (4)

And the $\lambda_i$ of formula (4) is:

$$\lambda_i = \left[\frac{1}{\lambda + 0.089} - \frac{0.035}{\beta^3 + 1}\right]^{-1}$$  \hspace{1cm} (5)

From the above formula, when pitch angle $\beta=0^\circ$ and tip speed ratio of $\lambda=6.325$ could get the maximum value of $C_{p\text{max}}=0.4382$. At this optimal point of $\lambda_{opt}$, wind turbine has transferred maximum energy form wind.

Also, the pitch control system is keeping turbine to track optimal tip speed ratio ($\lambda_{opt}$).

![Figure 1. Relationship of $C_p$ and $\lambda$.](image)

Large capacity PMSG wind turbine commonly uses the method of direct drive turbine. This is without gearbox, which can enhance reliable and reduce gearbox problems. Because of the drive structure, electromagnetic torque of the generator $T_e$ and viscous friction coefficient $B_f$ can affect the rotor mechanical speed $\omega_g$:

$$\frac{d\omega_g}{dt} = \frac{T_e - T_w - B_f\omega_g}{J_{eq}}$$  \hspace{1cm} (6)

The drive train of wind turbine and generator is rotor angular speed of the electric machine $\omega_e$ affects by rotor speed $\omega_g$ and the number of poles of $P_n$. $\omega_e$ equals to $\omega_m$ is the characteristic of direct drive wind turbines. It’s can be described as follow:

$$\omega_e = \omega_m P_n$$  \hspace{1cm} (7)

**Permanent Magnet Synchronous Generators Model**

The permanent magnetic synchronous generator dynamic equation are expressed in the "d-q reference" synchronous rotation coordinate system, this is expressed as[3]:

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\[
U_{sd} = R_i \cdot i_{sd} + L_i \cdot \frac{di_{sd}}{dt} - \omega_e \cdot L_i \cdot i_{sq}
\]

\[
U_{sq} = R_i \cdot i_{sq} + L_i \cdot \frac{di_{sq}}{dt} + \omega_e \cdot L_i \cdot i_{sd} + E_e
\]

In the formula shows, \(U_{sd}, U_{sq}\) is the stator voltages in d-q axis, \(i_{sd}\) and \(i_{sq}\) is the current in d-q axis, \(R_i\) is the generator resistance, \(L_{sd}, L_{sq}\) are d-axis and q-axis inductance respectively, \(\omega_e\) is the electrical angular velocity \(E_e = \omega_e \cdot \psi_f, \psi_f\) represents the permanent flux linkages.

The equation of the electromagnetic torque in the rotor is shown as:

\[
T_e = \left(\frac{3}{2}\right) \left(\frac{P_n}{2}\right) (L_{sd} - L_{sq}) i_{sq} \cdot i_{sd} - \psi_f \cdot i_{sq}
\]

The electromagnetic torque of the generator is only related to the stator current \(i_{sq}\), and the value of \(i_{sd}=0\), and the equation (9) can be expressed as:

\[
T_e = 1.5 P_n \psi_f \cdot i_{sq}
\]

According to equation (10), \(T_e\) is adjusted by \(i_{sq}\).

**Converter Model**

The permanent magnetic synchronous generator and grid are connected by AC-DC-AC PWM back-to-back converter. It converts the variable frequency current generated by the generator into constant frequency current suitable for the grid [4-5].

**Control Scheme of System**

**Generator Side and Grid Side Converter Control**

The variation of wind is so complex, and the way of make full use of low speed wind power concentration is depends on pitch control scheme and converter scheme. But the reaction of pitch controller is not easy to adjust frequently and rapidly. So, the system output reacts more steady and accurate which is need converter scheme more effectivity. Maximum Power Point Tracking (MPPT)
is used to keep wind turbine generator rotor speed $\omega_m$ operation at optimal tip speed ratio $\lambda_{opt}$ in generator side convertor control scheme. The relationship is expressed as:

$$\omega_{ref} = \omega_{m_{opt}} = \frac{\lambda_{opt} v_{wind}}{R}$$

(11)

For obtain maximum energy from wind, the signal difference of $\omega_{ref}$ and $\omega$ is calculates by PI controller for $i_{sq_ref}$. And this signal gets q-axis which put into PWM. At the same time, to improve the dynamic response, we input voltage feed-forward compensation signal into PWM . And it produces control signal for generator, which is adjust to optimal.[6-7]. The signals of controller voltages inputs into SVPWM produces switching signal for converter. The generator side control scheme is shown as Fig.4.

![Figure 4. Generator side converter control scheme.](image)

The grid side converter is help the active power P and Q to adjust grid, and also keep DC-link voltage stabilize when change in wind speed and load transients. At this part, PI controller bring DC voltage into correspondence with reference value. The grid side converter base on synchronous rotating reference frame, which preset as follows:

$$u_d = e_d - Ri_d - \omega L i_q - L \frac{di_d}{dt}$$

$$u_q = e_q - Ri_q - \omega L i_d - L \frac{di_q}{dt}$$

(12)

In equation, all elements are based on the d-axis and q-axis. $e_d$ and $e_q$ are inverter voltage, $u_d$ and $u_q$ are voltage, $i_d$ and $i_q$ are current in d and q axis. R and L are the resistance and inductance respectively, $\omega$ is electrical angular velocity. Active power P and reactive power Q are controlled by $i_d$ and $i_q$ in the control scheme. The grid voltage space vector only considers d-axis, so $e_q=0$. The grid side converter control scheme of current loop and voltage loops is show as Fig.5.
The Improvement Design of PI Controller

Conventional PI controller output is the linear regulator, and provides absence of statistical offset errors, it is shown in Fig.6. But the defect is obvious, it reaches saturation in complex environment or signal changes frequently so easy that appears windup phenomenon and causes the decreasing of performance. And the PWM controller can’t produce a fine PWM waveform according to the future dynamic behavior, due to the lag of PI regulator. Due to this defect, improvement focus on the way to reduce windup phenomenon. We present a novel model of nonlinear PI controller, it is separately control every parts [8-9].

Add the part of back-calculation gain for reduce the integrator windup effect at the complex environment. The improvement design of Nonlinear PI controller for anti-windup is shown in Fig.7.

Simulation and Results

By making use of MATLAB to build the PMSG wind turbine generation system model, we have compared conventional PI controller with nonlinear PI controller for anti-windup. The signal of wind variation and PWM inputs in pitch controller and convorctor controller of voltage and current closed loop control. The parameters of the direct drive PMSG wind turbine generation system as follows: PMSG Rated Power=2102 kW; Radius of the Turbine Blades R=57m; Inductances $L_{sd}=L_{sq}=2.7$Mh; Stator Phase Resistance $R_s=0.00665$ Ω.

Compare Fig.8 with Fig.9, the two wind turbine generation system simulation results present nonlinear PI controller for anti-windup shows more rapidly reaction and smoothing and stabilize under changing environment.
In generator side, the output reaction of nonlinear PI controller for anti-windup system is more rapidly and more smooth of amplitude wave form at $i_q$ and $i_d$. Also, at grid side, the nonlinear PI controller for anti-windup system has better adaptability and resistance interference at $U_{dc}$ and $i_{abc}$.

The graphical results verified our new controller can have better adaptability and reaction for achieved the control goal of less feedback period and more smoothing output.

**Conclusion**

This paper presented the mainstream model of direct drive PSMG wind generation system in Matlab/Simulink. Not only the model has realized the unit grid-connected function under variation wind and captured the maximum energy as wind speed changes, but also the generator side controller and grid side controller can keep constant. This paper proposed the design method of a new-type controller for converter to improve system performance. The experiment results indicate the conclusion that the new-type controller can improve the performance of wind turbine generation system adaptability and resistance interference.

**References**


