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Research Article

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Study on the New Maximum Power Tracking for Variable Speed Wind Generator system

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ABSTRACT

In view of the problems that tip speed ratio (TSR) control can't achieve maximum output power and hill climb searching (HCS) control could not meet both rapidity and accuracy at the same time, this paper proposes a novel wind energy maximum power point tracking (MPPT) approach combining TSR control with search algorithm. The approach has not only the characteristics of simple and easy to implement, but also has advantages of fast convergence and high precision to mode search control. Speed tracking controller is designed by the feedback linearization to quickly track to optimized speed. According to the results of experimental tests, the control strategy could achieve maximum output power with the fast dynamic response.

Key words: MPPT; HCS; TSR control; search algorithm; feedback linearization.

INTRODUCTION

In order to improve the wind utilization efficiency, wind power generation usually adopts MPPT control within the rated power. For direct-drive wind generation system, the most common MPPT approach mainly have TSR control, HCS control and Small Signal Perturbation control [1-6]. HCS controls well without the wind turbine aerodynamic characteristics and the generator characteristics, but has two serious problems such as the speed-efficiency tradeoff and the wrong searching direction. The appropriate step size is mostly important for wind energy tracking [4]. If the step size is large, the maximum power point could not track accurately. But if the step size is set too small, tracking speed will be so slow that could not track the wind change. Many researchers have been studying on the improvement of the HCS control, but most all are too complex to use generally, which could not acquire the better performance[7].

TSR control is a widely used for the MPPT control which has the advantages of simple and easy to implement. The optimum rotor speed is acquired by the optimum tip speed ratio, and then must be quickly tracked for the maximum wind energy. While the larger maximum wind energy means not the higher output power, which is real objective of the wind generator system. Especially when the load power is larger, the maximum system output power curve will seriously deviate from the power curve of the maximum wind energy capture.

This paper proposes a novel MPPT algorithm including TSR control, Searching control and the speed tracking control. The optimized speed reference can be given by the TSR control, Searching control. And the speed tracking controller is designed by the Feedback Linearization. Finally, the proposed approach has be carried validation on the wind generation simulation and experiment platform.

THE PRINCIPLE OF NOVEL MPPT ALGORITHM

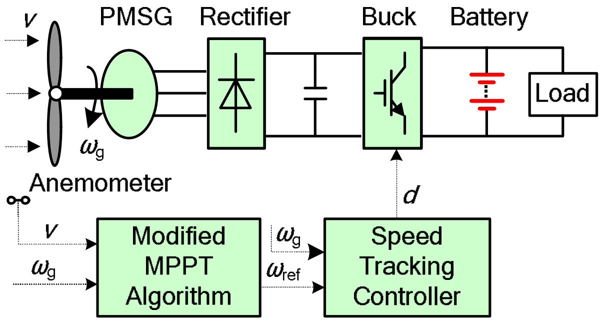

Fig.1: Structure and the Novel MPPT principle of the Wind Generation System

Combining the modified MPPT algorithm with speed tracking controller, a novel MPPT algorithm is proposed to acquire the maximum output power of the variable-speed wind generator system using diode bridge rectifier and Buck converter (As shown in Fig.1). TSR control and the Searching Algorithm(SA) are combined as the modified MPPT algorithm. The maximum wind energy can be acquired by the TSR control, while the maximum system output power is obtained by the SA. And then the optimized speed can be acquired to send speed tracking controller as the speed reference. The speed tracking controller is designed to track the optimized speed through the adjustment of buck converter duty. Due to the stochastic operation conditions and uncertainties in the system, the nonlinear controller must be designed by the feedback linearization for the fast dynamic characteristics.

THE MODIFIED MPPT SEARCHING ALGORITHM

The modified MPPT is proposed to acquire the maximum output power, which is combined TSR control with SA. TSR control makes the wind generator run in the maximum wind energy capture, while the SA is used to search the maximum output power. The SA is a direct search method with the strong local search ability. According to wind speed and turbine characteristic curve, the optimized speed of the TSR control can be acquired and then SA will search the ultimate optimized speed of the maximum output power from the optimized speed of the TSR control. The modified MPPT algorithm can be running the following two modes.

1. TSR tracking mode[8-11]

TSR control principle is shown in figure 2. According to the fixed pitch wind turbine energy capturing principle, there exists optimal TSR λ_{opt} and the C_{pmax} which corresponds to the maximum wind energy capture. Where the C_{pmax} is the maximum utilization coefficient of the wind energy, which is a function of λ_{opt}. The maximum wind energy can be represented as:

$$P_{wmax} = k_{\text{opt}}\omega_{\text{opt}}^{3} \tag{1}$$

The parameter k_{opt} is defined as

$$k_{\mathrm{opt}} = \frac{0.5\rho\pi R^5 C_{\mathrm{pmax}}}{\lambda_{\mathrm{opt}}^3} \tag{2}$$

The torque can be represented as:

$$T_w = \frac{1}{2}\rho\pi R^3 v^2 C_T \tag{3}$$

Where R is the radius of wind turbine, v is the wind velocity, ρ is air density and the C_T is the torque coefficient.

When the wind speed is v, the optimized generator speed corresponding to maximum wind energy can be obtained by

$$\omega_{\mathrm{opt}} = \frac{v\lambda_{\mathrm{opt}}}{R} \tag{4}$$

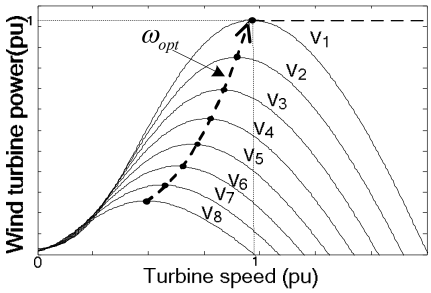

Fig.2: Tip Speed Ratio Control

2. Searching Algorithm

When the wind turbine speed ω has been closed to ω_{opt}, the MPPT will be working in this mode for the maximum output power. The procedure of the SA can be run as follows:

step 1：Initial step length, contraction factor and permissible error can be set respectively as δ0, α and ε, and the k=0.

step 2：Choosing j=1，$y=\omega_{opt}$ as the initial point, the system output power $P(y_j)$ can be calculated.

step 3：Speed positive detection. Setting $\omega=y+\delta_k$ as the speed reference, the $P(y+\delta_k)$ can be acquired through measurement DC voltage and current. If $P(y+\delta_k)$ is greater than P(y)，the y will be updated by the $y+\delta_k$, and the search process will enter the fifth step, otherwise the fourth step will be adopted.

step 4：Speed negative detection. Setting $\omega=y-\delta_k$ as the speed reference, the $P(y-\delta_k)$ can be acquired. If $P(y-\delta_k)$ is greater than P(y)，the y will be updated by the $y-\delta_k$, and the search process will enter the fifth step, otherwise the fourth step will be adopted.

step 5：Detection times examination. If j is less than the number of detection, the j will be set as j + 1, and then the search process returns to the third step. Otherwise, supposing $x_{k+1}=y$, the step six will be adopted.

step 6：Pattern movement. If $P(x_{k+1})>P(x_k)$, pattern movement can be realized along the direction of the acceleration $x_{k+1}-x_k$ from the x_{k+1}. if the conditions are $y=2x_{k+1}-x_k$, $\delta_{k+1}=\delta_k$, k=k+1, j=1, the search process return to the third step, or else to Step Seven.

step 7:Termination criterion judgment. When the δ_k is smaller than ε, the pattern search will be ended, and the optimized speed can be obtained. Otherwise the Step Eight will be accepted.

step 8：Step size shortening. If x_{k+1} is equal with the x_k, the conditions of $\delta_{k+1}=\alpha\delta_k$ and k=k+1 can be given, then the process return to the second step. Else if $x_{k+1}\neq x_k$, the conditions of $x_{k+1}=x_k$, $\delta_{k+1}=\delta_k$, k=k+1 can be given, the second step can be returned too.

SPEED TRACKING CONTROL

Wind turbine MPPT approach must have the ability to fast tracking speed reference, so the speed tracking controller can be designed through the feedback linearization.

The model of the permanent magnet synchronous generator with the Buck converter can be expressed as：

$$\frac{di_s}{dt}=k_e\omega-\frac{R_s i_s}{L_s}-\frac{\pi u_b}{3\sqrt{3}L_s}d \tag{5}$$

Where is i_s the stator current; k_e is the voltage coefficient; u_b is the voltage of the battery; d is duty of the Buck; R_s and L_s are the impedance and inductance of generator one-phase.

The speed dynamic model of the wind generator system can be written as:

$$\frac{d\omega}{dt}=\frac{1}{J_w}\left(0.5\rho\pi R^3V^2C_T-k_g i_s\right) \tag{6}$$

Where J_w is inertia moment of the wind turbine.

The dynamic model of Wind generator system can be defined as[12]

$$\begin{cases}\dot{x}=f(x)+g(x)u\\ y=h(x)\end{cases} \tag{7}$$

Where $f(x)=\begin{bmatrix}k_e\omega-\dfrac{R_s i_s}{L_s}\\ \dfrac{1}{J_w}\left(0.5\rho\pi R^3V^2C_T-k_g i_s\right)\end{bmatrix}$; $g(x)=\begin{bmatrix}-\dfrac{\pi U_{dc}}{3\sqrt{3}L_s}\\ 0\end{bmatrix}$; u=d; $h(x)=\omega$ 。

Lie derivative of the speed can be acquired by

$$\begin{aligned}\dot{y}&=L_f h(x)+L_g h(x)u\\ &=\frac{1}{J_w}\left(0.5\rho\pi R^3V^2C_T-k_g i_s\right)\end{aligned} \tag{8}$$

In view of $L_g h(x)=0$， Lie derivative of the $\dot{y}$ can be acquired by

$$\ddot{y}=L_f\dot{y}+L_g\dot{y}u=A_1(t)+E_1(t)u \tag{9}$$

Where $A_1(t)=\frac{1}{J_w}\left(-k_g\left(k_e\omega-\frac{R_s i_s}{L_s}\right)+\frac{0.5\rho\pi R^3v^2}{J_w}\frac{\partial C_T}{\partial\omega}\left(0.5\rho\pi R^3V^2C_T-k_g i_s\right)\right)$; $E_1(t)=\frac{\pi k_g U_{dc}}{J_w 3\sqrt{3}L_s}$;

Set $v=\ddot{y}$ and $e=\omega_{ref}-\omega$;

Then $v=\ddot{\omega}=k_4\mathrm{e}-k_1\dot{\mathrm{e}}+k_{\mathrm{a}}\int\mathrm{e}dt$;

And the Buck duty can be calculated by

$$u=\frac{k_4e-k_1\dot{e}+k_{\mathrm{a}}\int edt-A_1(t)}{E(t)} \tag{10}$$

EXPERIMENTAL STUDY

As shown in Fig.3, the experiment test rig of wind power generation system is set up to prove MPPT algorithm, which consists of 7.5 kW Siemens frequency converter, 7.5kW asynchronous motor, reduction box, 5kW permanent magnet generator and other measurement devices(current, voltage and speed).

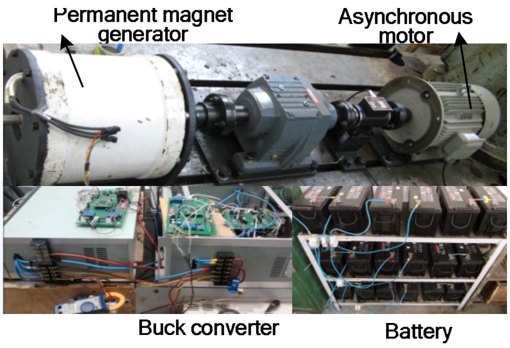

Fig.3: Experiment Rig of Wind Generation System

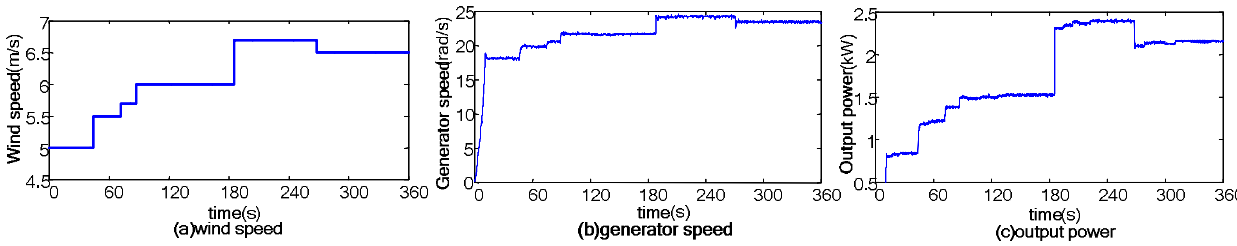

Fig.4: Experiment Results

The experimental results are shown in Fig.4. Fig.4 (a) gives wind speed variation, while Generator speed variation is shown in Fig.6 (b). Variation of system output power can be seen in Fig.6 (c). As shown in the Figure, it can be seen that system achieves the optimal speed after about 20 seconds when the wind speed changed. And then SA is beginning to search for the maximum output power from the speed of the TSR. Through the analysis of the result, combined TSR control with SA, the system can better achieve the maximum output power of wind generator system.

CONCLUSION

In this paper, two kinds of wind turbine MPPT control method widely used for small wind power generation system are analyzed respectively. But the traditional HCS control can not meet both rapidity and accuracy，and the TSR control can not achieve maximum real output power. This paper proposes a new MPPT approach combined TSR control with search algorithm, and designs speed tracking controller through the feedback linearization for the fast track to set speed. Through experiment verification, the method realizes the maximum output power with great tracking effect on wind speed change.

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