An Optimal Maximum Power Point Tracking Algorithm for Wind Energy System in Microgrid

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ABSTRACT

To increase the efficiency of a wind energy conversion system (WECS), the maximum power point tracking (MPPT) algorithm is usually employed. This paper proposes an optimal MPPT algorithm which tracks a sudden wind speed change condition fast. The proposed method can be implemented without the prior information on the wind turbine parameters, generator parameters, air density or wind speed. By investigating the directions of changes of the mechanical output power in wind turbine and rotor speed of the generator, the proposed MPPT algorithm is able to determine an optimal speed to achieve the maximum power point. Then, this optimal speed is set to the reference of the speed control loop. As a result, the proposed MPPT algorithm forces the system to operate at the maximum power point by using a three-phase converter. The simulation results based on the PSIM are given to prove the effectiveness of the proposed method.

1. Introduction

Nowadays, the need for renewable energy resources, especially wind energy, is growing rapidly. In the wind energy conversion system (WECS), the mechanical power is extracted from the wind turbine, and then, this power is converted to electrical power. Although the wind power is abundant, it varies continually due to the variation of wind speed, and also, the output power of wind turbine is fluctuating. Thus, the maximum power point tracking (MPPT) is required to make the output power of wind turbine be the maximum value irrespective of the wind speed variation.

This paper presents an optimal MPPT algorithm for WECS not only to eliminate the need of wind speed sensor and wind turbine parameters but also to deal with the condition of a sudden wind speed change. The proposed MPPT algorithm employs the instantaneous power of wind turbine and the angular speed of generator as inputs. The power of the wind turbine can be generally obtained by measuring the angular speed and the torque in the wind turbine. To obtain the torque of the wind turbine without requiring the additional torque sensor, the torque observer is employed in this paper, which is employed in the proposed MPPT algorithm through the calculation of output power of wind turbine. The effectiveness of the proposed method is proved through simulation results.

2. Wind Turbine

The mechanical power generated by a wind turbine can be expressed as [1]

$$P_m = \frac{1}{2}\rho\pi R^2 C_p(\lambda,\beta)V^3 \tag{1}$$

where ρ is the air density, R is the radius of wind turbine, C_p is the power coefficient, λ is the tip speed ratio, β is the blade pitch angle, and V is the wind speed. The tip speed ratio λ is given by

$$\lambda = \frac{\omega_m R}{V} \tag{2}$$

where ω_m is the turbine rotor speed.

To capture the maximum mechanical power of wind turbine, the power coefficient C_p should be maintained to the maximum value $C_p^{\max}$ at given wind speed. This is achieved by maintaining λ to an optimal value λ^{opt} at fixed pitch angle. For this purpose, the rotor speed of wind turbine should be changed according to the change of wind speed to obtain λ^{opt}.

3. Torque Observer and Proposed MPPT Algorithm

The dynamic equation of the generator is given as

$$T_m^{gen} = J\frac{d\omega}{dt} + B\omega + T_e^{gen} \tag{3}$$

where T_m^{gen} is the mechanical torque of generator, T_e^{gen} is the electromagnetic torque of generator, ω is the generator rotor speed, J is the inertia, and B is the viscous friction coefficient. Assuming that there is no gearbox, the mechanical torque of wind turbine T_m will be directly transmitted to generator. Hence, (3) can be rewritten as

$$T_m = J\frac{d\omega}{dt} + B\omega + T_e^{gen} \tag{4}$$

To estimate the mechanical torque of wind turbine, the disturbance observer is employed as [2]

$$\dot{\hat{\boldsymbol{x}}} = \boldsymbol{A}\hat{\boldsymbol{x}} + \boldsymbol{B}u + \boldsymbol{K}\left(y - \boldsymbol{C}\hat{\boldsymbol{x}}\right) \tag{5}$$

where $\hat{\boldsymbol{x}} = \left[\hat{\omega} \quad \hat{T}_m\right]^T$ and $\boldsymbol{K} = \left[k_1 \quad k_2\right]^T$ is the observer gain matrix.

Fig. 1 shows the proposed MPPT algorithm, in which

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the estimated power output $\hat{P}_m[k] = \omega[k] \cdot \hat{T}_m[k]$ is used based on the estimated torque $\hat{T}_m$.

The proposed MPPT algorithm shown in Fig. 1 can be explained by using Fig. 2.

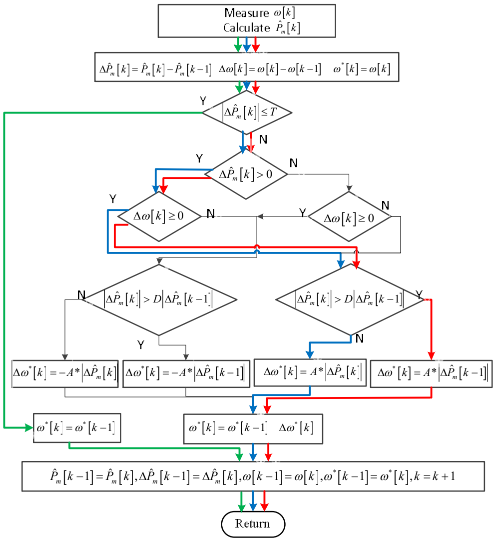

Fig. 1 The proposed MPPT algorithm.

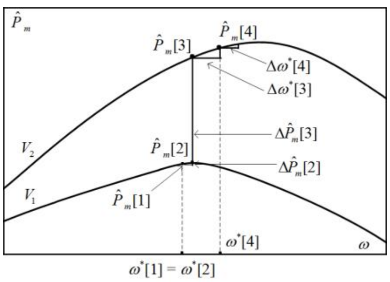

Fig. 2 Tracking steps of the proposed MPPT algorithm.

Initially, the wind speed is V_1 and the output power is $\hat{P}_m[1]$ under operating speed $\omega^*[1]$. At next step, the ouput power $\hat{P}_m[2]$ can be calculated from the estimated torque $\hat{T}_m[2]$. When $\Delta\hat{P}_m[2]$ is relatively small and within the threshold value $\pm T$, the proposed MPPT algorithm does not change the generator speed and this operation is illustrated by green lines in Fig. 1.

When the wind speed changes suddenly to V_2, the operating point changes from $\hat{P}_m[2]$ to $\hat{P}_m[3]$ due to the large inertia of turbine. Since $\Delta\hat{P}_m[3]$ is large and positive at this instant, the wind speed change can be detected in the proposed algorithm by comparing the present power variation $\Delta\hat{P}_m[3]$ with the previous one $\Delta\hat{P}_m[2]$. In order to avoid the fluctuation in tracking procedure, $\Delta\omega^*[3]$ is calculated proportionally to $\Delta\hat{P}_m[2]$. The positive $\Delta\omega^*[3]$ indicates that the generator speed should be increased to reach the maximum power point (MPP). These tracking steps are shown by red lines in Fig. 1. When the power variation is not quite, the proposed scheme maintains the generator speed as illustrated in tracking steps in blue lines of Fig. 1.

The determined optimal generator speed ω^* in Fig. 1 is set to the reference value of speed controller in three-phase converter as shown in Fig. 3.

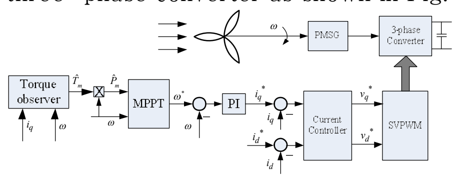

Fig. 3 Control block diagram of three-phase converter.

4. Simulation Results

To validate the effectiveness of the proposed MPPT algorithm, the simulation has been carried out under the variation of wind speed as shown in Fig. 4. Fig. 5 indicates that the power coefficient is maintained to its maximum value irrespective of wind speed variation. As a result, the maximum output power can be drawn from the wind turbine.

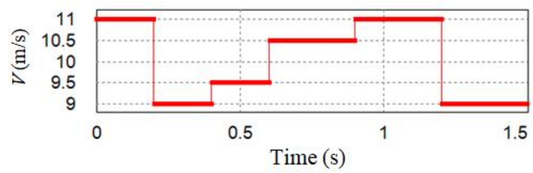

Fig. 4 Variation of wind speed.

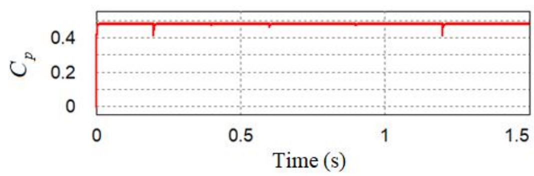

Fig. 5 Power coefficient with the proposed MPPT algorithm.

5. Conclusion

This paper has presented an optimal MPPT algorithm for a WECS. This proposed MPPT algorithm is achieved by investigating the directions of changes of the mechanical output power in wind turbine and rotor speed of generator. The torque observer is used to estimate the mechanical torque of wind turbine. The simulation results confirm the effectiveness of the proposed method.

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6. References

[1] K. Tan and S. Islam, "Optimum control strategies in energy conversion of PMSG wind turbinesystem without mechanical sensors," IEEE Trans. Energy Conversion, vol. 19, no. 2, pp. 392-399, Jun. 2004.

[2] K. Ogata, Modern Control Engineering, 5th ed. Upper SaddleRiver : Prentice Hall, 2010.