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Efficiency-enhanced Dynamic MPPT for Wind Power System under Middle-low Wind Speeds

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ABSTRACT
Under middle-low wind speeds condition, which is in the middle and lower sections of MPPT wind speed field, efficiency of wind power system is very low. This restricts the utility of this type of wind energy resource. Based on the relationship between DFIG wind power system efficiency and DFIG rotor rotation speed, a new MPPT with dynamic matching method was introduced to enhance the power conversion efficiency, which includes a certain turbine kinetic energy accumulation and release cycle. This method transfers turbine kinetic energy from lower rotation speed to higher rotation speed to convert mechanical energy into electrical energy by generator, which has higher efficiency. Base on theoretical analysis and simulation, the new dynamic MPPT method is proven to exhibit totally higher electrical efficiency than conventional MPPT.

Keywords: DFIG wind power system, Middle-low wind speed, Dynamic maximum power point tracking, Dynamic matching method, Efficiency enhancement

NONMENCLATURE

MPPT	Maximum Power Point Tracking
DFIG	Doubly Fed Induction Generator
PMSG	Permanent Magnet Synchronous Generator

1. INTRODUCTION

Improving wind power efficiency under middle-low wind speeds, which is in the lower and middle sections of MPPT (Maximum Power Point Tracking) wind speed field, has been a research focus recently. Since wind energy resources under middle-low wind speeds are more widely distributed in geography and time domain, especially in onshore wind energy field. However, currently the efficiency of wind power system is low under middle-low wind speeds, which limits the utilization of these wind energy resources.

For middle-low wind speed condition, conventional MPPT technology was used in wind power system, which requires wind turbine to work at a certain rotation speed to capture maximum wind energy. Although wind turbine gets the maximum mechanical energy from wind, the conversion efficiency of the generator which transfers mechanical energy to electrical energy is low, so the overall efficiency is relatively low from wind energy to electrical energy at middle-low wind speeds.
In this paper, the relationship between DFIG efficiency and rotor rotation speed was analyzed. Then a new MPPT with dynamic matching method was introduced. Finally, simulation was performed to verify the effectiveness.

2. DFIG EFFICIENCY AT MIDDLE-LOW WIND SPEEDS

DFIG wind power system is an important form of wind farms, including wind turbines, gearboxes, DFIG generator and associated equipment, as shown in Figure 2-1.

Firstly, wind turbine converts fluid form wind energy into turbine kinetic energy Pmech. The conversion efficiency is represented by the wind energy utilization coefficient Cp; according to the Betz's theorem, it is expressed as:

$$P_{mech} = C_P \rho V^3 S/2 \quad (1)$$

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Where, P_{mech} ---- Mechanical energy obtained by the turbine;

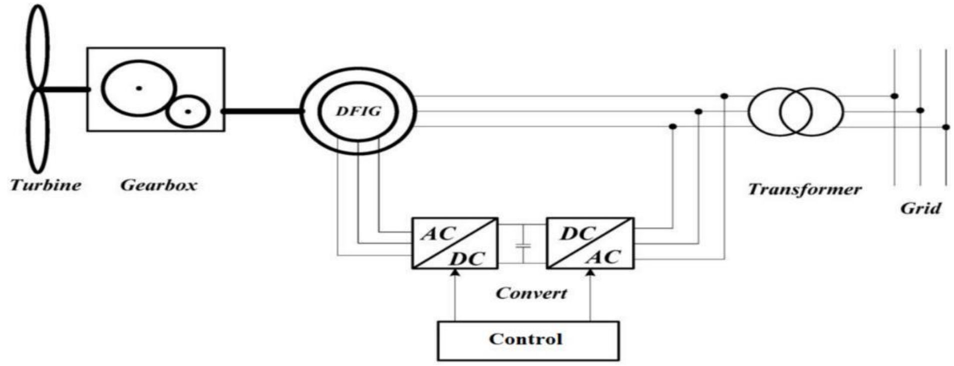

Fig.2-1 Diagram of DFIG wind power generation

C_P---- Wind energy utilization coefficient;

ρ ---- Air density;

V ---- Wind speed;

S ---- Sweep area of Wind turbine;

The relationship between turbine mechanical energy P_{mech} and turbine rotation speed is shown in Figure 2-2, where the wind speed $V_1 < V_2 < V_3$. Meanwhile, $\omega_{r1} < \omega_{r2} < \omega_{r3}$. That means the rotation speed of wind turbine should be low under low wind speeds to gain maximum energy from wind. This let generator enter low efficiency state. This is a serious problem caused by the conventional MPPT.

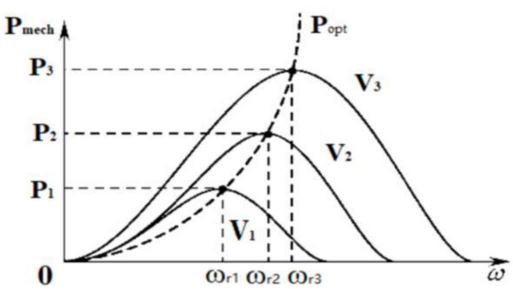

Fig.2-2 Relationship between Turbine Rotation Speed and Mechanical Power at different wind speeds

A gearbox with a fixed gear ratio (for example 70, 140,and so on) is used in DFIG system to connect wind turbine with DFIG rotor. So, the rotation speed of DFIG rotor is proportional to the rotation speed of wind turbine. However, DFIG generator efficiency is relatively low when rotation speed of DFIG rotor is low. This results in a lower efficiency of the DFIG system at low wind speed. This is a problem under middle-low wind speeds. As shown in Fig. 2-3, the lower and middle sections of MPPT zone are accompanied by low rotation speed of DFIG rotor. This is caused by low rotation speed of wind turbine under middle-low wind speeds.

The efficiency of DFIG power system under middle-low wind speeds is shown in Fig.2-4, which were obtained by simulations based on GE's DFIG wind power system model. At different wind speeds, the efficiency of DFIG wind power system is different.

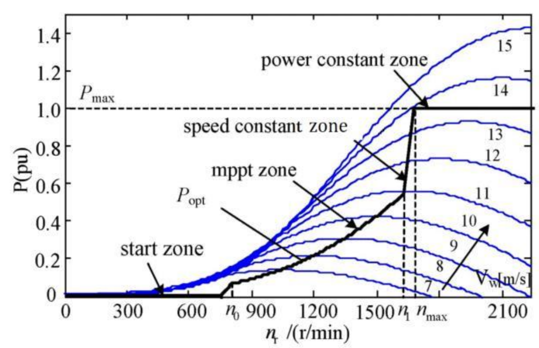

Fig.2-3 Rotation Speed of DFIG Rotor and MPPT Zone

As shown in Fig. 2-4, efficiency curve drops rapidly from 7 m/s wind speed and at 4 m/s nearby the efficiency curve keep low state. This shows the DFIG wind power system efficiency under middle-low wind speeds with conventional MPPT. Dynamic Modeling of GE 1.5 Wind Turbine-Generator was used here [3].

Below a new method is proposed to improve the efficiency under middle-low wind speeds.

3. NEW MPPT WITH WIND TURBINE ENERGY STORAGE AND RELEASE CYCLE

The rotation speed of the wind turbine can be increased within a certain range under the action of wind, so the kinetic energy on wind turbine will be increased. Then wind power generator enters electric power generation state. The increased rotation speed of wind turbine will enhance the generator efficiency. As electric power generation works according to a specific curve, the rotation speed of the wind turbine will drop again. Then another energy storage and release cycle will start. This is shown in Fig.3-1, the cycle is “A->B->C->D”. This cycle can be called “Dynamic Matching Method”, since wind turbine always runs between ω_0 and $(\omega_0 + \Delta\omega)$ under a certain middle-low wind speed, rather than fixed ω_0.

Point A is determined by the conventional MPPT at the corresponding wind speed, which let wind turbine gain maximum mechanical energy from the certain wind speed. While the coordinates of points B, C and D and the curve from C to D are selected and determined by simulation, which aimed at maximizing electric power output.

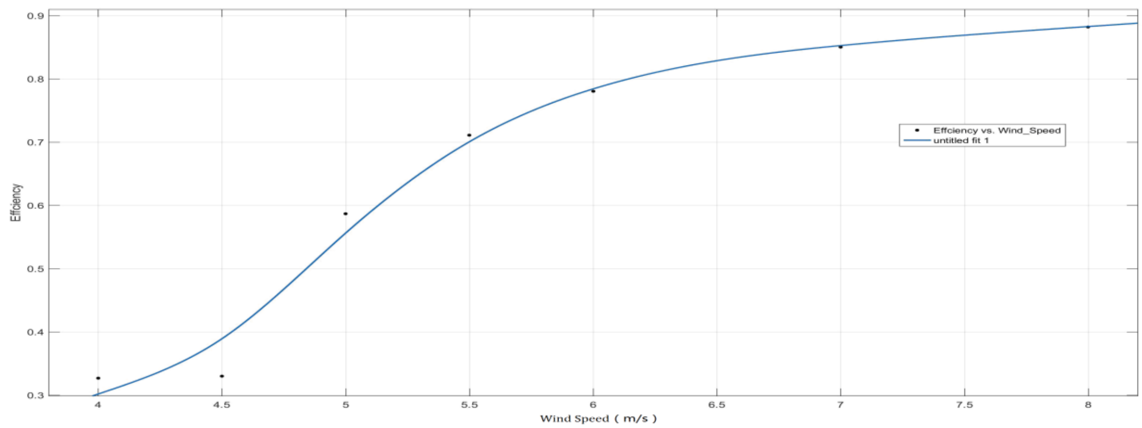

Fig.2-4 DFIG efficiency under different wind speed

Based on this principle, the new dynamic MPPT can be designed. The energy store-release curve is shown in Figure 3-1. The parameters of the curve can be determined and optimized by simulation and experiments.

In Fig.3-1, the vertical axis is the output power and the horizontal axis is the rotation speed of the wind turbine. From point A to B, the accelerating stage of accumulating energy is to accumulate wind energy on the blades of the wind turbine to increase the turbine rotation speed; From point C to D is the working mode of turbine kinetic energy was released and electric power was output from generator. The straight-line segments from D to A and from B to C are the switch of the two working modes. These two working modes are reciprocating cycle.

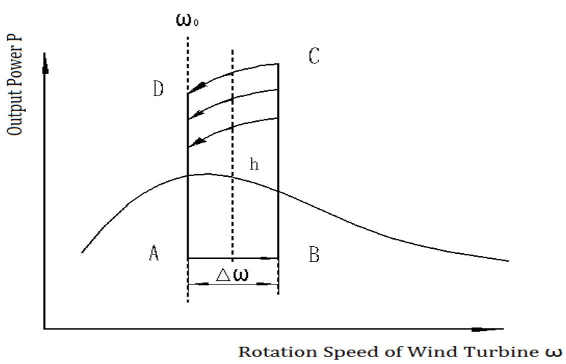

Fig.3-1 New MPPT principle with wind turbine energy storage and release cycle curve based on DFIG

The curve CD is a selected special curve, and each nominal medium and low wind speed has a specific curve CD corresponding to it. The curve CD can be a quadratic curve or polynomial curve with a high point C and a low point D. The curve CD is specifically represented as follows:

$$P = (a_n * \omega^n + a_{n-1} * \omega^{n-1} + \cdots + a_1 * \omega + a_0) + h \qquad (2)$$

Where, a_n is a constant, $n \geq 1$;

ω is the rotational speed of wind turbine;

h is the amplitude of generator output power;

P is the value of generator output power.

The heights of every points on the curve CD determines the magnitudes of the power output of the wind turbine. The curve CD is higher near point C, which let turbine mechanical energy quickly output to electric energy through generator, while the curve CD is lower near the point D and let wind turbine keep a longer work time to obtain more wind energy with less power output. This method utilizes wind turbine to transfer wind energy captured near point D and point A to output electricity near point C, thereby improving overall efficiency. Because the turbine rotation speed near the C point is higher, the efficiency of the generator is also higher. Near the point D, efficiency of wind turbine to obtain wind energy is higher. In conclusion, the curve CD just takes advantage of both sides and transfers the efficiency "Peak-Valley matching" with conventional MPPT to "Peak-Peak matching" with new MPPT method.

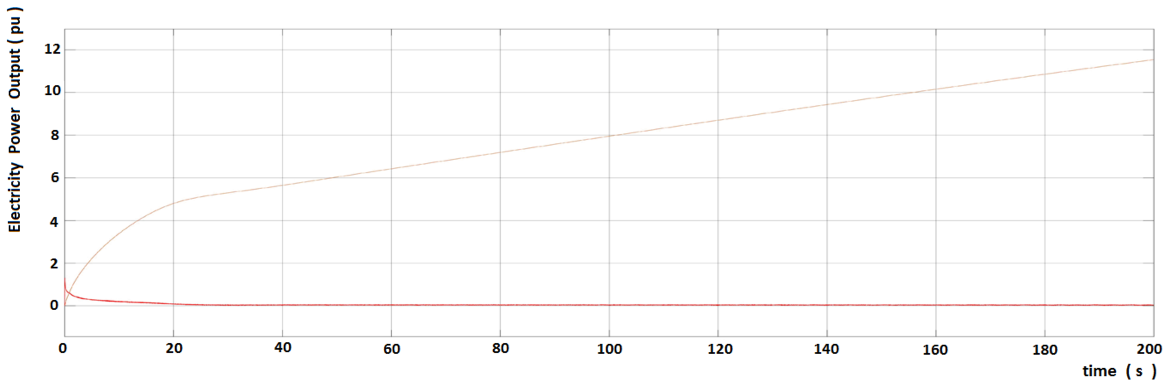

Fig.4-1 Electricity Output from DFIG under Conventional MPPT

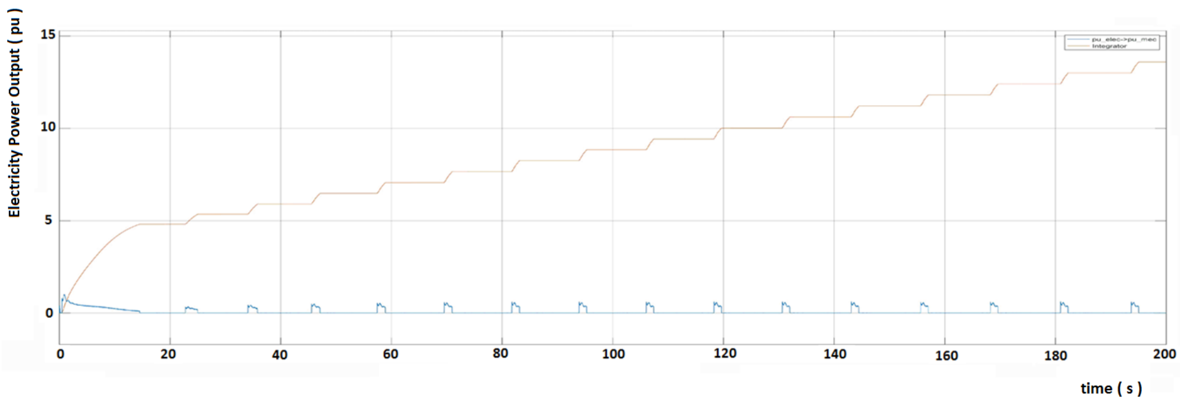

Fig. 4-2 Electricity Output from DFIG under New MPPT Method

4. VERIFY WIND POWER EFFICIENCY WITH NEW MPPT METHOD AT MIDDLE-LOW WIND SPEEDS

To verify the effectiveness of new MPPT method at middle-low wind speeds condition, simulation of DFIG wind power generation was established based-on MATLAB/SIMULINK software. These simulation results were compared with those simulation results under conventional MPPT. Dynamic Modeling of GE 1.5 Wind Turbine-Generator was used in simulations [3].

Under the wind speed of 5m/s, the power output of the DFIG generator under the conventional MPPT control and the total energy obtained within 200 seconds, the simulation results are shown in Figure 4-1. In Figure 4-1, the red line is the power output of the DFIG generator, and the orange line is the total energy obtained for 200 seconds. The total energy obtained here is 11.53 in pu unit.

In the figure, the starting section on the left side is the initial state, and the right side is the steady state. The above two figures show that efficiency improvement of 32.58% is achieved for the new MPPT, compared with the conventional MPPT under 5m/s steady-state conditions.

For each wind speed of 4~8m/s, the efficiency improvement is obtained through simulation, as is shown in Figure 4-3. Below 8 m/s wind speed, the new MPPT has good efficiency improvement. The lower the wind speed, the higher the improvement. At 4m/s wind speed, 40% improvement is achieved.

As for gradual wind, efficiency improvements are shown in Figure 4-4 based on simulation results. In the left simulations, the wind speed is smoothly increased from 4m/s to 5m/s in 200 seconds, and the right simulations, from 6.5m/s to 7.5m/s. Improvement is more obvious near the wind speed of 4m/s.

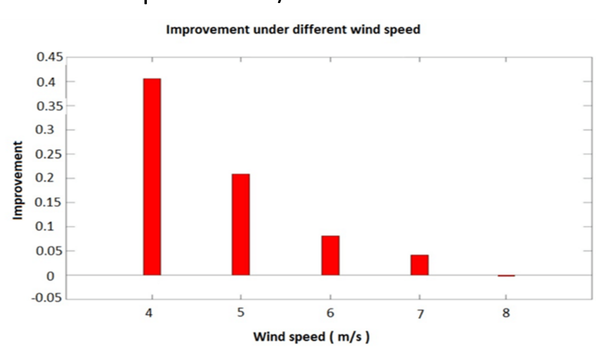

Fig.4-3 Efficiency improvement under different wind speeds

About engineering implementation of new MPPT method:based on research results, store parameters of new MPPT under every wind speed in the wind power system controller. Measure the wind speed V and select the parameters of new MPPT at nearby nominal wind speed.

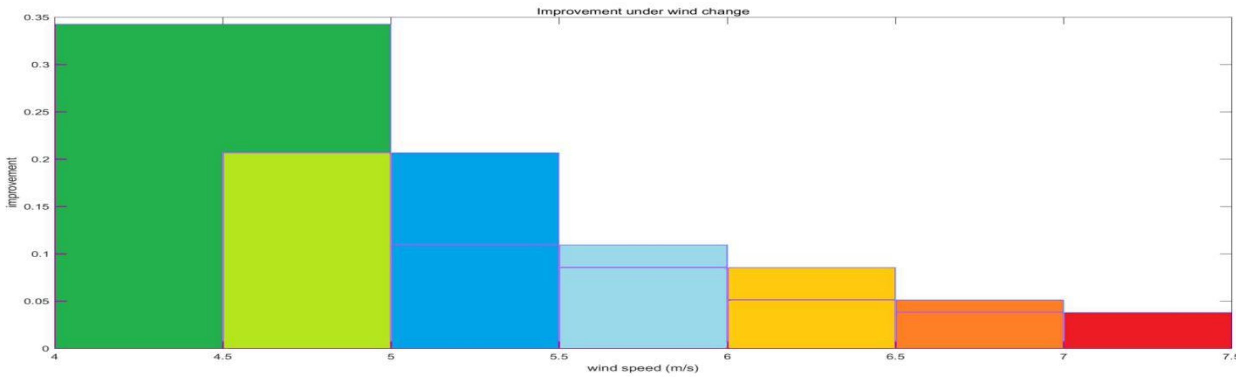

Fig.4-4 Efficiency improvement under gradual wind

The complex wind speeds can be decomposed into various sections of wind speeds respectively to deal with, which is like the gradual wind situation.

Under the new MPPT method, the power output becomes discontinuous, which can use multiple wind turbines of the wind farm to produce an overall smooth power output.

The research in this paper is based on DFIG power system, moreover, the relevant conclusions also can be applied to the PMSG wind power system.

5. CONCLUSIONS

5.1 Under middle-low wind speeds, the DFIG wind power system has a low efficiency with conventional MPPT, because rotation speeds of wind turbine and DFIG rotor are relatively low.

5.2 A new dynamic MPPT with wind turbine energy storage-release cycle was introduced in this paper and electrical energy efficiency has been improved under middle-low wind speeds conditions.

5.3 As for gradual wind, the new dynamic MPPT also has obvious efficiency improvements within middle-low wind speeds range, that means the new MPPT method has good robustness with the wind speed changes in a certain range.

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Biography

The corresponding author of this paper Dr. Yingtang Li is now working as an Associate Professor at Lanzhou University of Technology. His research interests are Energy and Information Technology. He had been worked in Energy Technology Department of Aalborg University (AAU), Denmark as guest researcher for one year.