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Using Asynchronous Generators with a Wound-Rotor to Convert Wind Energy into Electricity

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ABSTRACT: This article describes the advantages of using asynchronous generators with a wound rotor to convert wind energy into electrical energy . At the same time, the difference in the equivalent equivalent circuits of an asynchronous generator with a wound rotor and asynchronous generators with a squirrel-cage rotor is compared. In addition, the characteristic of extracting maximum electromagnetic power from a wound-rotor induction generator by changing the rotor circuit resistance at different wind speeds is presented.

KEYWORDS: rotor circuit, slip ring, rotor circuit resistance, wound-rotor induction generator, Matlab .

I. INTRODUCTION

This type of wind turbine, also called Type 2 wind turbine, uses a wound rotor induction generator. It differs from a squirrel-cage induction machine in that the rotor windings are not short-circuited and have windings that can be energized through slip rings and brushes, as shown in Figure 1. The rotor windings are then connected to an external three-phase resistor bank. The resistor block contains variable resistors, the resistance of which can be changed from zero to the maximum equivalent resistance R_E in each phase. The control logic will be described in more detail later on. For high reliability, it is not advisable to use resistors that are changed mechanically. Instead, the current in the rotor winding is controlled by an electronic converter. The actual resistance is a fixed value, but the electronic switching device makes it variable on the rotor side.

A variation of this type is that external resistors and power electronics, slip rings are mounted on the rotor of the machine, requiring regular maintenance and eliminates the use of brushes, but now control signals must be transmitted wirelessly to the rotor to control external resistance, and the additional heat is dissipated inside the rotor (making it difficult to cool the machine). To increase the speed range of WTs and decrease stress on mechanical components, the wind energy industry developed semivariable-speed Type 2 WTs with WRIG (Fig. 1). The system configuration is similar to a Type 1 WT except that the SCIG is replaced by WRIG and rotor windings are connected to the converter-controlled variable resistor through slip rings and brushes. The power converter is realized by a three-phase diode-bridge rectifier and an insulated gate bipolar transistor (IGBT)-based chopper circuit. The Type 2 configuration is often called Optislip WT.

As shown in Fig. 2, the change in the rotor resistance (R) affects the torque/slip characteristic of the WRIG. The equivalent value of R seen by the rotor varies with the duty cycle of the chopper. With different values of R, the WRIG can operate at different operating points. As the rotor resistance is increased, the slip of WRIG increases; therefore, the speed of WRIG increases up to 10% above the synchronous speed. The power rating of converter is proportional to the speed range achieved. For example, a 1000 kW Type 2 WT needs a power converter of 100 kW capacity (10% of total power). It should be noted that the power converter assists in changing the rotor resistance and it does not process the generator output power.

With higher speed range, the WT captures slightly higher power from the wind with reduced stress on mechanical components. The wear-and-tear of gearbox and bearings is reduced and life cycle is increased due to semivariable speed operation. The semivariable speed range also leads to less effect on grid frequency. However, the

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initial cost of Type 2 WECS is higher than Type 1 WECS due to power converter in rotor circuit. The losses in rotor resistance lead to less system efficiency. This configuration needs more frequent maintenance due to slip rings and brushes in WRIG. Some WT manufacturers mount rotor resistance circuit on the rotor shaft to decrease maintenance requirements for slip rings and brushes [5, P 102-110]. However, the generator requires extra cooling to compensate the heat produced by resistor. The WRIG cannot perform smooth grid connection and consumes reactive power similar to the SCIG. Therefore, this configuration also requires soft starter and reactive power compensation similar to Type 1 WECS. The reliability of overall system decreases due to more number of components.

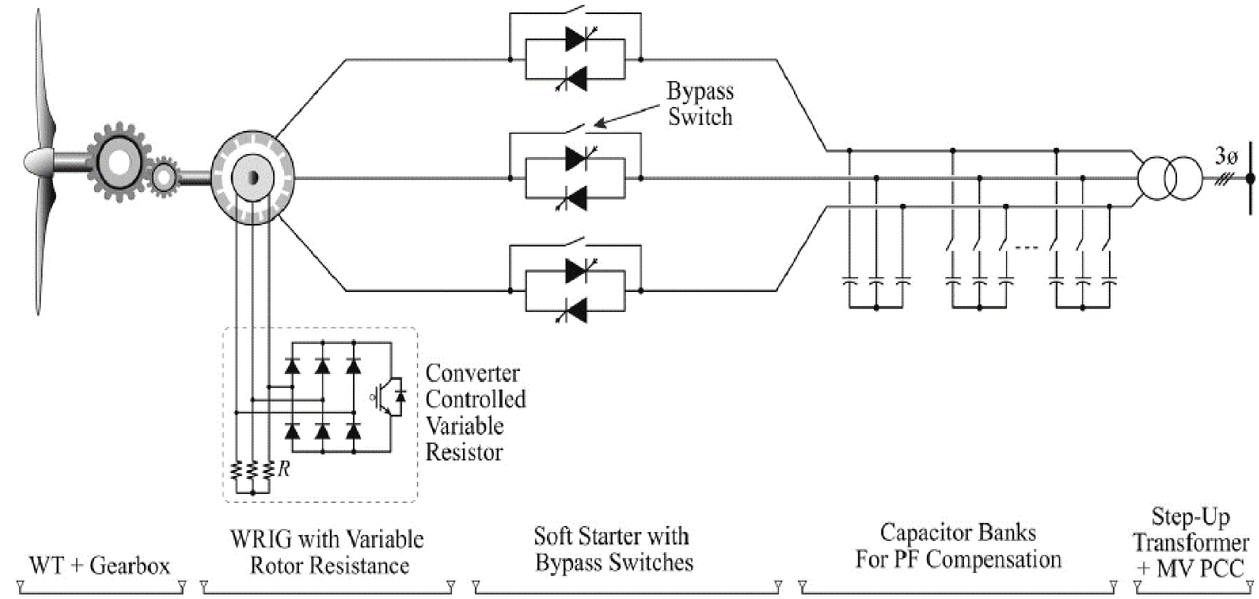

Fig.1. A type of asynchronous wind generator with a wound rotor

II. METHODS

The WRIG with variable rotor resistance is also commercialized up to couple of MWs. A few examples of commercial solutions are Vestas V66 (2.0 MW) and Suzlon Energy S88 (2.1 MW). This configuration is also becoming obsolete because of its limited speed range and low energy conversion efficiency.

The first difference is that $R'_э / s$ there is a variable external resistance on the rotor side. Its variability comes from two sources, namely slippage and the ability to control the R_E value . The second difference is that the rotor parameters now relate to the stator winding parameters , i.e. X'_2 or I'_r. This is due to the fact that all rotor quantities must be transferred to the stator windings, as in the equivalent circuit of a transformer.

The reduction coefficient depends on the ratio of the number of stator and rotor windings. In particular, if the external resistance $R'_э$ has a real value, then it $R'_э = \left(\frac{w_1}{w_2}\right)^2 \cdot R_э$ will be the value used in the equivalent circuit. Similarly, the reflected rotor current is $I'_2 = \left(\frac{w_2}{w_1}\right) \cdot I_2$. This circuit can be calculated using the same methods used for a squirrel cage induction machine.

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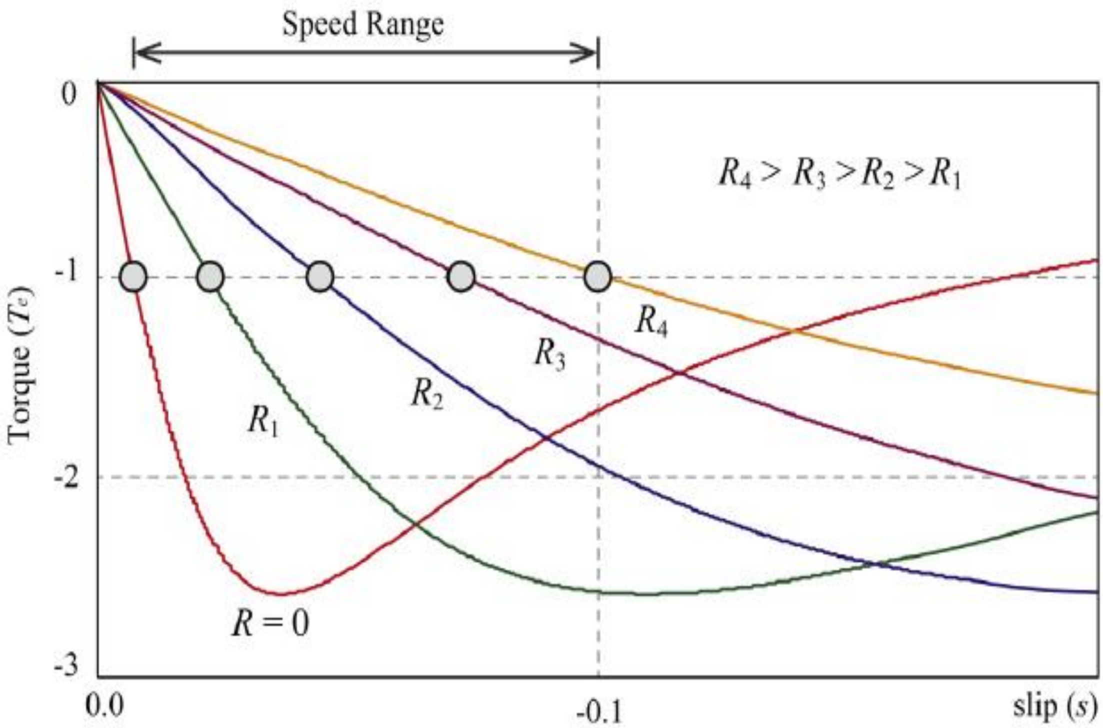

Fig.2. Torque–slip characteristics of WRIG with converter-controlled variable rotor resistance R.

According to Figure 3 above, the equivalent circuit of this type of generator has two significant differences from the equivalent circuit of a squirrel-cage induction machine: In $R'_{2rot} = R'_2 + R'_e$ the equations R_2 we need to replace with In particular, in the rotor windings and external resistances. $3I_r'^2 R'_{2rot}$ equal power is converted into heat. Another component $3I_r'^2 \frac{1-s}{s} R'_{2rot}$ is related to electromechanical energy conversion.

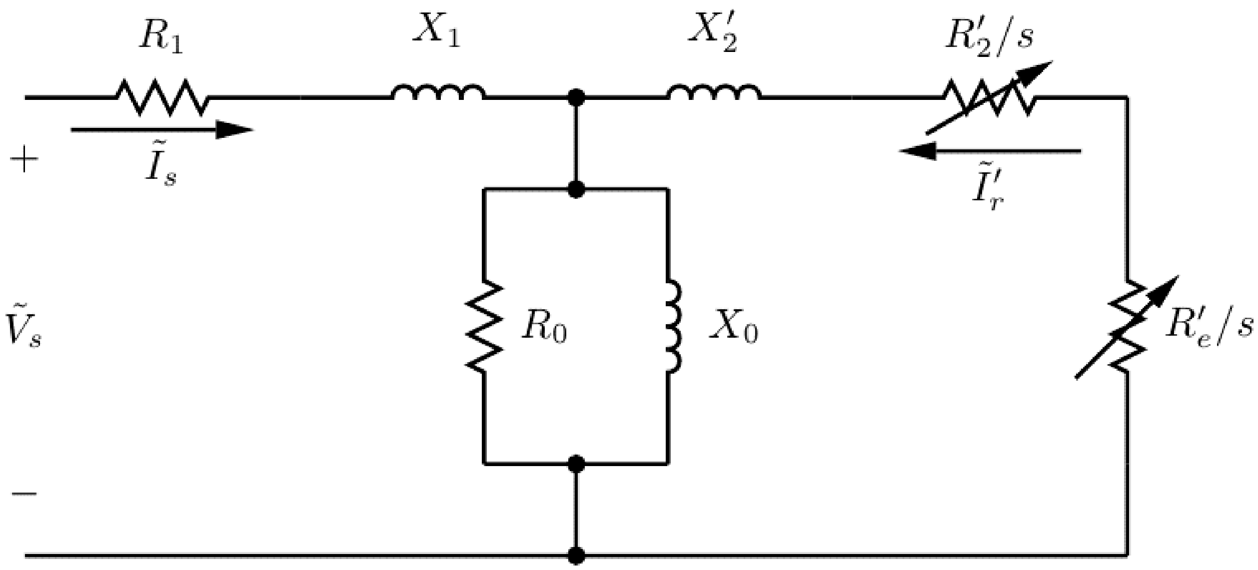

Fig.3. Stationary equivalent circuit of an asynchronous machine with a wound rotor

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III. RESULTS AND DISCUSSION

The main feature of an asynchronous generator with a wound rotor is that its mechanical characteristics can be changed by adjusting the value of external resistance. Below Figure 4 shows the mechanical characteristics of an asynchronous machine with a wound rotor with a power of 2.2 kW in generator and motor modes, obtained using the Matlab program.

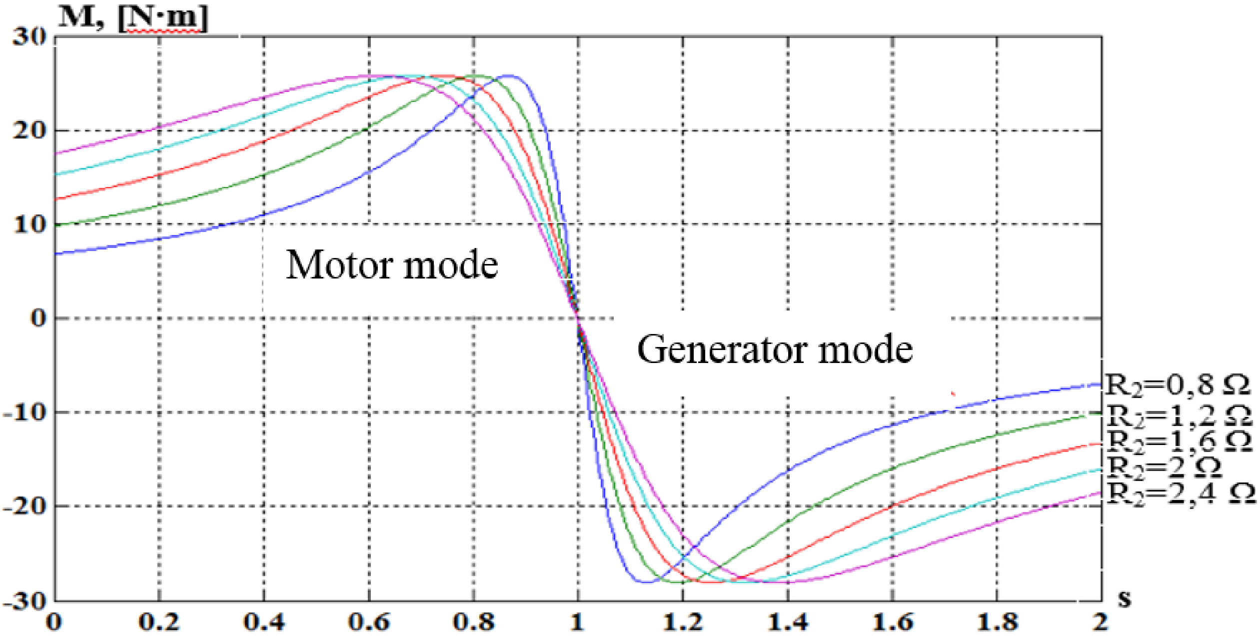

Fig.4. Electromagnetic torque of a 2.2 kW phasor induction machine in motor and generator modes

Figure 4 above shows that due to changes in the resistance in the rotor circuit, its maximum electromagnetic torque remains unchanged both in engine mode and in generator mode. But here, due to the change in speed, the electromechanical power of the generator changes. Using this feature of a wound rotor induction motor, maximum electrical energy can be obtained from variable wind energy.

Converting wind energy into electricity requires us to pay more attention to the power versus speed curve, which has an interesting shape as shown in Figure 5 below. In this case, according to Figure 5, we can use phased rotor induction generators as variable speed wind turbines, which allows us to extract more energy from the wind flow. To optimally utilize wind energy at any wind speed, this is done based on the change in the amount of external resistance corresponding to that speed.

The following example shows how to design a wind turbine to achieve this goal.

Let's assume that at a wind speed of 3 m/s we operate the generator with the optimal gear ratio and negligible slip. When the wind speed is less than 3 m/s, the external resistance is zero, but with a further increase in wind speed we $R'_{э}$ We start to increase.

If the rotor speed is close to synchronous for 3 m/s, then for 3.8 m/s it must be 3.8/8 = 1.26 times higher, otherwise the slip will be −25%.

First, since the relative speed of the gearbox $\lambda^* = \frac{\omega_\omega R_d}{v_1}$ is , $\omega_\omega = \frac{\lambda^* R_d}{v_1} = \frac{7,6 \cdot 4}{3} = 10,13$ we can find the wind speed of the blade in rad/s. In this case, the relative speed of the gearbox is $G = \frac{\omega_{rm}}{\omega_\omega} = \frac{86,25}{10,13} = 8,5$.

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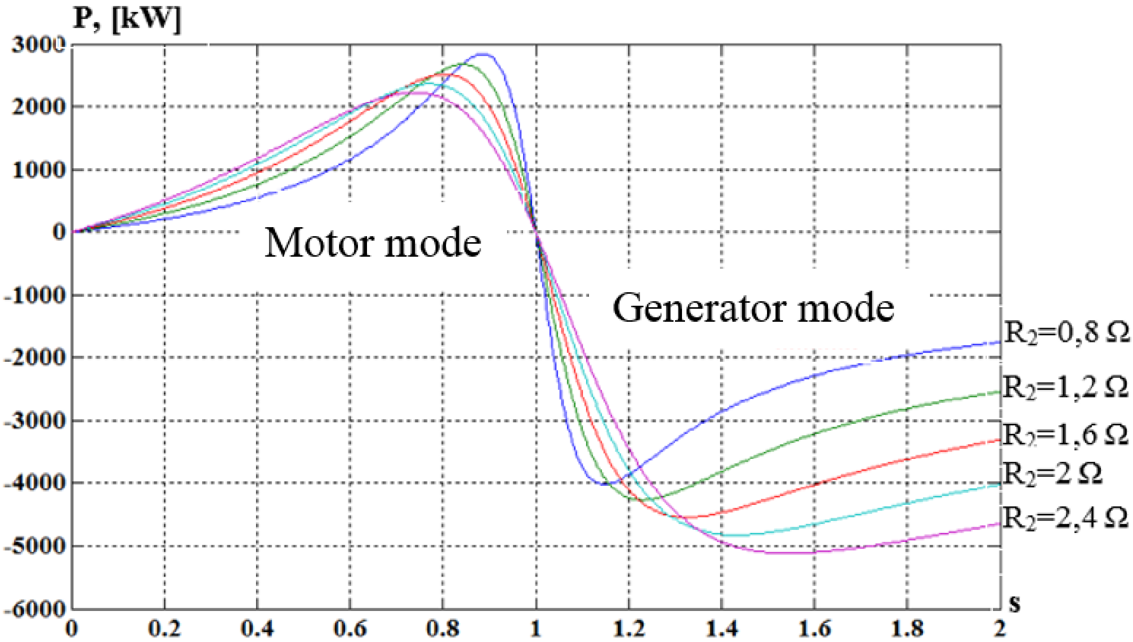

Fig.5. Characteristics of the dependence of the electromagnetic power of a phase-rotor induction machine on the rotation speed and active resistance of the rotor circuit

The next step is to determine the value for each wind speed to obtain the maximum power. R_2' This can be done through a simple process of trial and error.

The results are presented graphically in Figure 5.

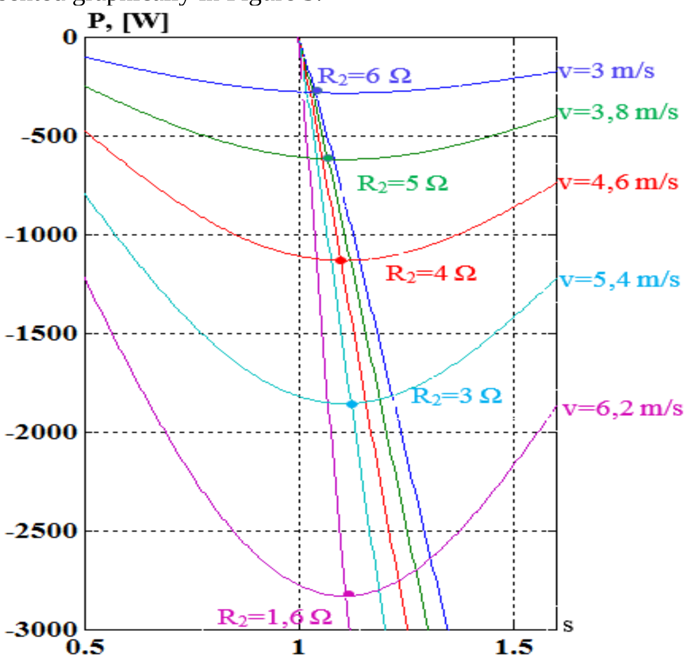

Fig.6. Characteristics of the selection of maximum electromagnetic power from a phase-shifting asynchronous generator due to changes in the resistance of the rotor circuit at different wind speeds

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VI. CONCLUSION

According to the characteristic obtained in Figure 5 above, we see that in asynchronous generators with a wound rotor it is possible to obtain maximum electromagnetic power at different wind speeds by changing the resistance of the rotor circuit. Buesa means that this type of generator is superior to other types of generators. In addition, using this method, it is possible to obtain a certain amount of energy even when the wind speed is less than the minimum.

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