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Control and Implementation of Dual Stator-Winding Induction Generator System

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ABSTRACT: The dual-stator-winding induction generator (DWIG) designed to achieve wide-speed-range operation with reduced capacity of the static power controller is presented. The DWIG consists of a standard squirrel-cage rotor and a stator with two separate windings wound for the same number of poles. The dc bus on the control-winding side and the dc bus on the power-winding side are connected in parallel to further widen the speed range of the constant dc voltage output, especially at low speeds. Based on the control mechanism of the DWIG and the instantaneous power theory, control-winding-flux-orientation control strategy is employed. In order to improve the wind energy conversion efficiency at low wind speeds, the generator efficiency optimization method is investigated. The experimental results from a 20 kW/600 V prototype show that the proposed generating system can output the constant dc voltage in a speed range of 1:4, and the generator efficiency in the low speed range is improved, which both bring the advantages for wind power applications, such as expanding the scope of the wind energy utilization and capturing much more wind energy.

KEYWORDS: Control-winding-flux orientation, dc generating system, dual stator winding, efficiency optimization, induction generator (IG), wide-speed-range operation, wind power

I. INTRODUCTION

Wind generators (WGs) have been widely used both in autonomous systems for power supplying remote loads and in grid-connected applications. Although WGs have a lower installation cost compared to photovoltaic, the overall system cost can be further reduced using high-efficiency power converters, controlled such that the optimal power is acquired according to the current atmospheric conditions. The WG power production can be mechanically controlled by changing the blade pitch angle. However, WGs of special construction are required, which is not the usual case, especially in small-size stand-alone WG systems. A commonly used WG control system is shown in Fig. This topology is based on the WG optimal power versus the rotating-speed characteristic, which is usually stored in a microcontroller memory. The WG rotating speed is measured; then, the optimal output power is calculated and compared to the actual WG output power. The resulting error is used to control a power interface. In a similar version found in the WG output power is measured and the target rotor speed for optimal power generation is derived from the WG optimal power versus rotor-speed characteristic. The target rotor speed is compared to the actual speed, and the error is used to control a dc/dc power converter.

In permanent-magnet WG systems, the output current and voltage are proportional to the electromagnetic torque and rotor speed, respectively. In the rotor speed is calculated according to the measured WG output voltage, while the optimal output current is calculated using an approximation of the current versus the rotational-speed optimal characteristic. The error resulting from the comparison of the calculated and the actual current is used to control a dc/dc converter. The disadvantage of all above methods is that they are based on the knowledge of the WG optimal power characteristic, which is usually not available with a high degree of accuracy and also changes with rotor aging. Another approach using a two-layer neural network updates online the preprogrammed WG power characteristic by perturbation of the control signals around the values provided by the power characteristic. However, under real operating conditions where the wind speed changes rapidly, the continuous neural network training required results in accuracy and control-speed reduction.

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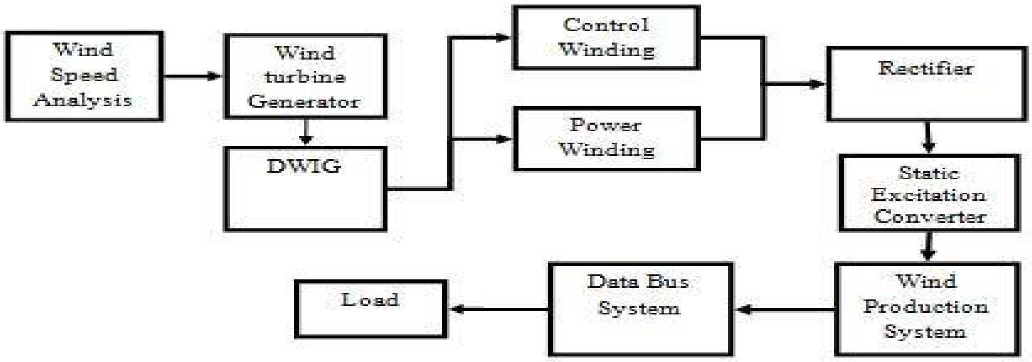
II. BLOCK DIAGRAM

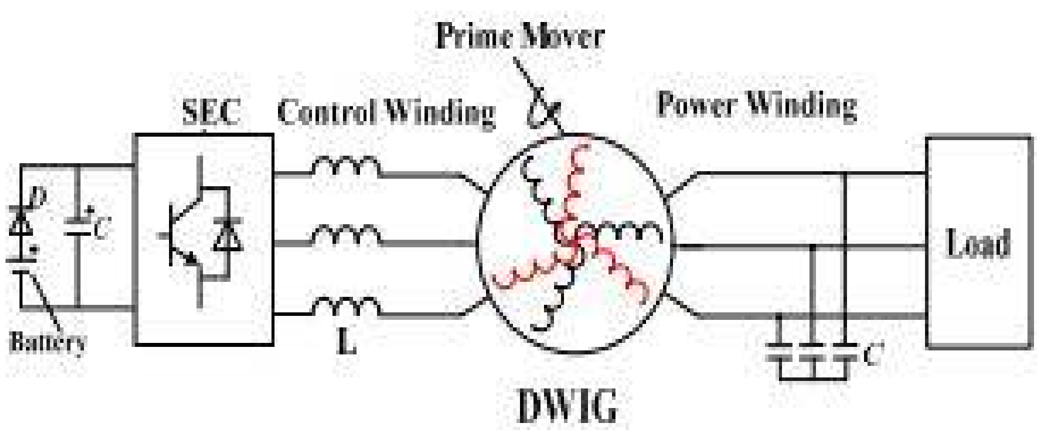


A. STATIC EXCITATION CONVERTER (SEC)

To get constant frequency and constant voltage electricity under the changes of speed and load, it suffers from the complexity or low efficiency due to the use of a discharge resistance or battery. For aircrafts, ships and wind power applications, a DWIG-based dc generating system with one or more diode rectifiers connected to the power winding is recently explored. This system has a good performance of the dc voltage output with a small-size power converter under the variations of speed and load, which shows that it can also be used in wind power systems, especially as a potential solution for the offshore wind farms using the HVDC transmission.

B. DWIG

The dual-stator winding induction generator(DWIG) at the beginning of this century overcome the shortcomings of traditional cage-type induction motor, arouses widespread concern in academics by its unique structure, and the optimized design of this generator, voltage control strategy, the system stability and variable-speed operation have been studied deeply. According to the current study, the generation system consisting of DWIG has better performance. Because its output is stable DC power, it can be transmitted by the way of HVDC, which can be applied for offshore wind power generation. In the usual 3/3-phase DWIG system, the power windings have only three phases, and it is connected to a rectifier load, which causes larger harmonic current and harmonic MMF. When it is applied to wind power, there exist lots of vibrations and noise in the system.



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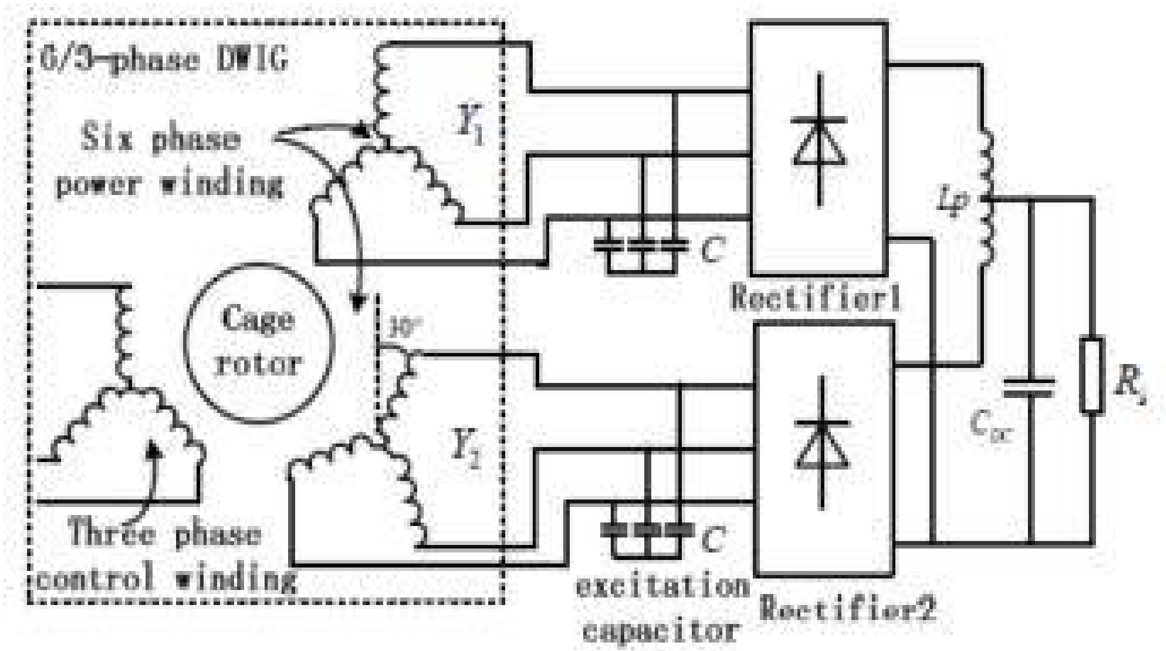
DWIG SYSTEM



In the DWIG, two sets of stator windings are present, and an SEC is connected to the control winding, which results in increased complexity of the voltage buildup process when compared with a traditional IG. Considering that no-speed sensor exists in this system, the entire voltage buildup process is divided into three steps, namely, frequency search, generation in an open loop, and generation in a closed loop.

III. EFFICIENCY OPTIMIZATION FOR PROPOSED GENERATING SYSTEM IN THE LOW SPEED RANGE

To reduce losses and improve efficiency, the efficiency optimization should be considered, especially for the wind power systems, of which the generator often operates in a wide speed range, including high and low speeds because of the instability and variation of wind energy. According to the aforementioned analysis, when the proposed generating system is applied to wind power systems, there is a problem that, although it is able to output the constant dc voltage at low speeds, the generator efficiency, compared with that in the high speed range, would decrease greatly with the decreases of speed and load in the low speed range, which to some extent would limit its advantage for the wide-speed-range operation.

Fortunately, for the proposed generating system, the SEC has the voltage-boosting ability, and at low speeds, it can make the system output voltage keep constant and reach the command value even if the control-winding voltage is low and variable, which brings the possibility of efficiency optimization to the DWIG operating at low speeds with light load. Therefore, in the low speed range, the efficiency optimization for the proposed generating system is focused.

A. POWER WINDING AND CONTROL WINDING

The power winding feeds power to the dc load through a diode rectifier. A fixed excitation capacitor bank is connected across the terminal of the power winding to provide partial reactive power. On the control-winding side, the SEC is connected to produce variable reactive power, through which the regulation of the reactive power in different working conditions is achieved. DWIG's wide-speed-range operation will result in the great change of excitation current produced by the capacitor bank and will lead to the large variation of the capacity of SEC. Therefore, the selection of the excitation capacitor should be deeply thought of to make the capacity of SEC minimal.

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In addition, how to make the DWIG system work in the wide speed range is one of the other important issues discussed in this paper. Flux is the only linkage connecting the two sets of windings. Oriented by the control-winding flux, instantaneous power theory is employed to analyze the control mechanism for a wider operating speed range. The control strategy is then set forth, through which a careful manipulation of output voltage in a wide speed range can be realized.

IV. CONTROL STRATEGY FOR PROPOSED GENERATING SYSTEM OPERATING IN WIDE SPEED RANGE

For the proposed system, to keep the output dc voltage constant in a wide speed range with the load variation is one of main control objectives, and to maintain the dc bus voltage of the SEC stable is the basic condition for the normal work of the SEC.

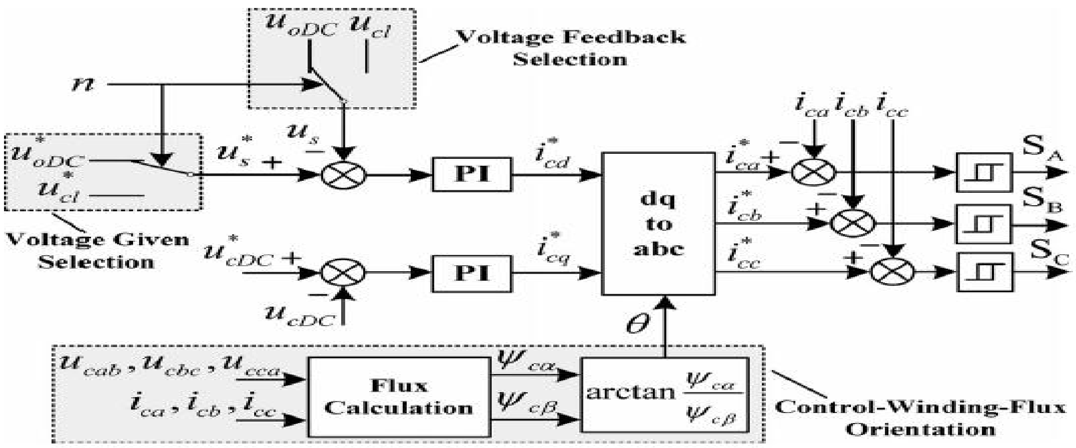
In the DWIG, the two sets of stator windings share the same air-gap flux; thus, any change of the control-winding flux would cause the corresponding change of the air-gap flux and power winding flux, which can regulate the power-winding voltage, power-winding rectified voltage, and control-winding voltage. Moreover, the stability of the dc bus voltage can be guaranteed by the regulation of the control-winding active power, which can be implemented by adjusting the electromagnetic torque absorbed by the control winding. According to the control mechanism of the DWIG can be briefly expressed as

Using the instantaneous power theory the control winding instantaneous active power *pc* and the control-winding instantaneous reactive power *qc* in the *d*–*q* rotating coordinates oriented by the control-winding flux, as shown in Fig., can be expressed as

$$\begin{cases} p_c = \omega_1 \psi_c i_{cq} + i_{cd} \dfrac{d\psi_c}{dt} \\ q_c = \omega_1 \psi_c i_{cd} - i_{cq} \dfrac{d\psi_c}{dt} \end{cases}$$

where *icd* and *icq* are the *d*-axis and *q*-axis components of the control-winding current, respectively.

According to the DWIG, the control-winding absorbed electromagnetic torque and the control-winding flux are determined by the control-winding instantaneous active power and reactive power, respectively. Therefore, the basic idea of the CWFO control strategy for the DWIG can be briefly described as



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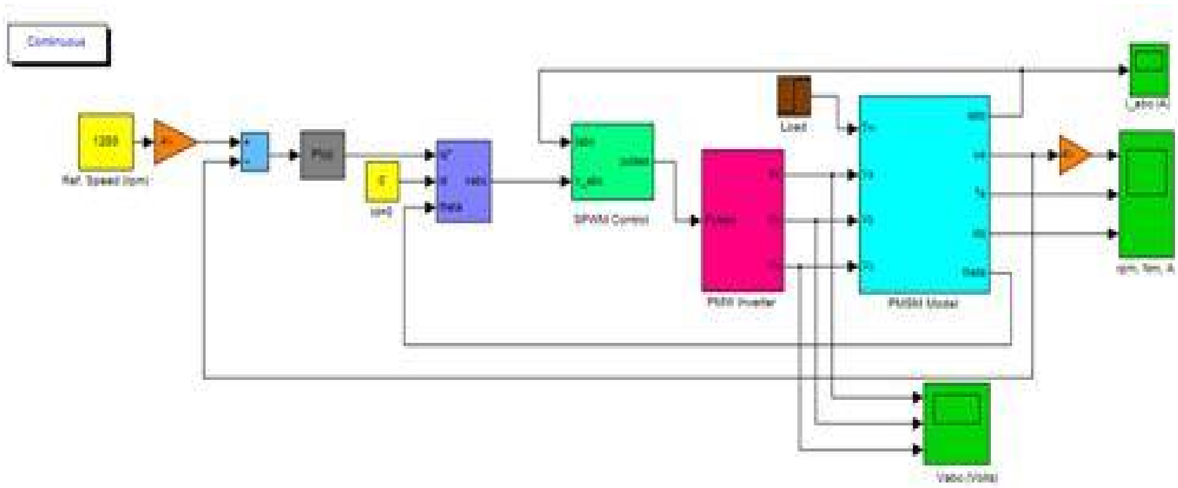
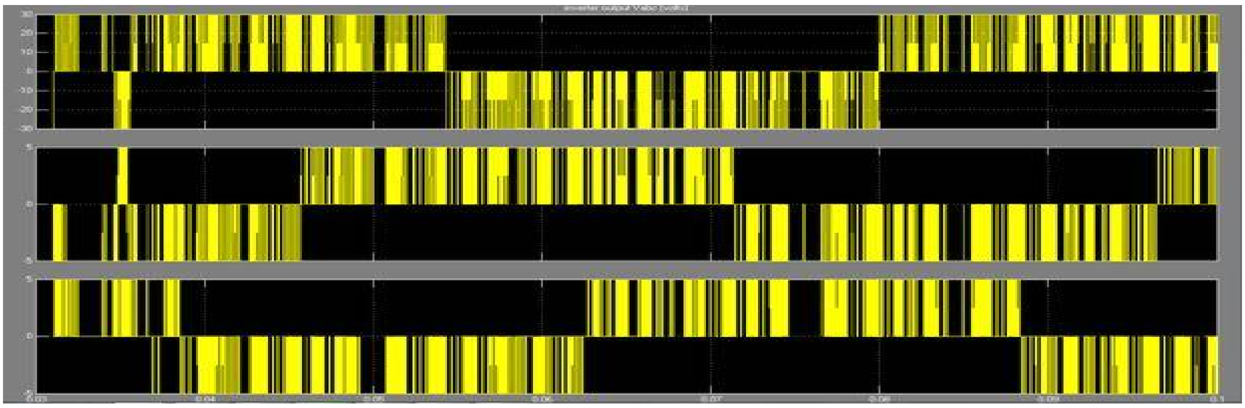
$$i_c \xrightarrow{\text{oriented by } \psi_c} \begin{cases} i_{cd} \rightarrow q_c \rightarrow \psi_c(\psi_p) \rightarrow u_p(u_{pDC}, u_c) \\ i_{cq} \rightarrow p_c \rightarrow T_{ec} \rightarrow u_{cDC} \end{cases}$$

V. SIMULATION OUTPUT



3 PHASE OUTPUT



VI. CONCLUSION

The DFIG system costs more than fixed-speed induction generators without converters. However, the performance and controllability are excellent in comparison with fixed speed induction generator systems; they capture more wind energy, they exhibit a higher reliability gear system, and high-quality power supplied to the grid. This paper has presented a solution for the DWIG system operating in a wide speed range. The flux is the crucial physical quantity that connects the two sets of windings. Oriented by the stator flux linkage, the system control mechanism is disclosed with the help of instantaneous power theory. Based on this, the system control strategy which is fit for the wide-speed-range operation is proposed. To improve the generator efficiency at low speeds for wind power applications, a corresponding efficiency optimization method based on the generator loss model is proposed. The experimental results from a 20 kW/600 V prototype show that the proposed generating system can output constant 600 V dc voltages in a speed range of 1:4, and the generator efficiency in the low speed range is improved. In addition, when this proposed generating system is applied to wind power systems, it can further expand the scope of wind energy utilization, and capture much more wind energy.

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