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DC-Voltage fluctuation elimination through a dc-capacitor current control for PMSG under unbalanced grid voltage conditions

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Abstract— Unbalanced grid voltage causes a large second-order harmonic current in the dc-link capacitors as well as dc-voltage fluctuation, which potentially will degrade the life span and reliability of the capacitors in voltage source converters.

This project proposes a novel dc-capacitor current control method for a grid-side converter (GSC) to eliminate the negative impact of unbalanced grid voltage on the dc-capacitors. In this method, a dc capacitor current control loop, where a negative-sequence resonant controller is used to increase the loop gain, is added to the conventional GSC current control loop. The rejection capability to the unbalanced grid voltage and the stability of the proposed control system are discussed. The second-order harmonic current in the dc capacitor as well as dc-voltage fluctuation is very well eliminated. Hence, the dc capacitor will be more reliable under unbalanced grid voltage conditions. A modular implementation method of the proposed control strategy is developed for the PMSG.

Index Terms—Current control method, dc link, PMSG

I.INTRODUCTION

With the continuous increased capacity of installed wind power, the effects of wind power generation on the grid are more and more considerable [1]. As a consequence, the grid codes issued by more and more power system operators specify that the wind turbines should withstand certain voltage disturbances such as voltage unbalance and voltage distortion without tripping. In order to do this, the wind turbine systems must continuously develop and improve their performance. With the continuous increased capacity of installed wind power, the effects of wind power generation on the grid are more and more considerable. As a consequence, the grid codes issued by more and more power system operators specify that the wind turbines should withstand certain voltage disturbances such as voltage unbalance and voltage distortion without tripping. In order to do this, the wind turbine systems must continuously develop and improve their performance. Due to the low power coefficient of wind turbines, power converters are required to transfer the maximum available power at the highest efficiency.

Unbalanced grid voltage causes a large second-order harmonic current in the dc-link capacitors as well as dc-voltage fluctuation, which potentially will degrade the lifespan and reliability of the capacitors in voltage source converters.

In this project a novel dc-capacitor current control method for a grid-side converter (GSC) to eliminate the negative impact of unbalanced grid voltage on the dc-capacitors is introduced. A modular implementation method of the proposed control strategy is developed for the PMSG controller. Finally, experiments are presented to validate the theoretical analysis. MATLAB software is used.

II. THE DEVELOPMENT OF WIND

The sun heats the air mass in the atmosphere. Because of the spherical shape, the rotation of the earth, the seasonal changes and local differences in solar radiation differences of pressure develop. This difference of pressure must be balanced. As there is a surplus of radiation at the equator balancing wind currents develop between the equator and two poles. Depending on the season these balancing wind currents are in a northern or southern direction, seen from the equator.

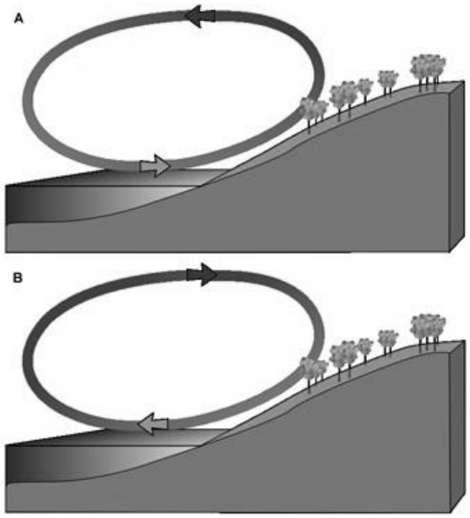

Fig 1. Development of Wind

These balancing wind currents are called wind. Particularly in January there are balancing wind currents on the northern hemisphere, because milder solar radiation causes area of low pressure. In July, the balancing wind currents can be observed in the southern hemisphere. These kind of balancing wind currents are called large-scale pressure differentials.

Local pressure differentials are often found in coastal areas. During the day, the mainland will heat more than water and because of this the equalising current between mainland and water develops. During the day the wind flows towards the mainland (See picture A). During the night the mainland is cooled more rapidly than the water, and because of this it comes to an equalising current in the opposite direction (See picture B

III. CALCULATING THE POWER OF THE WIND

Part of the kinetic energy of the wind is transformed into rotational energy by the rotors. These drive an electrical generator which changes the rotational energy into electricity.

$$E = \frac{\pi}{2} \times r^2 \times p \times v^3 \times t$$

This formula allows calculating the power of the wind. **P** stands for air density, **r** is the radius of the rotor, **v** the wind velocity and **t** is the time that it takes the wind to pass through the rotor blades.

With the kinetic energy of the wind and the degree of efficiency of the wind power station the largest production of energy can be calculated. The degree of efficiency of all wind power stations averages 59.30%. With the following formula the power which a wind power station is able to produce can be calculated:

The degree of efficiency of the wind power station multiplied with the kinetic energy of the wind results in the maximally producible power.

The lower limit of wind velocity for producing of electricity averages 35m/s. Less than 35m/s the wind power station is not able to produce electricity anymore. At more than 25m/s wind velocity the wind power station turns itself off to avoid damage. The optimum wind velocity averages 12 to16m/s.

IV. PROPOSED PMSG SYSTEM

Since the stator of a PMSG is directly connected to the grid, a negative sequence is added to the stator flux under unbalanced grid voltage conditions. As a consequence, larger negative-sequence currents flow through the stator and rotor, which cause a significant second-order harmonic fluctuation in the electromagnetic torque and powers. Then, the torque fluctuations cause wear and tear of the mechanical components such as gearbox and shaft. In addition, the active power fluctuations, which flow through the capacitors of the dc link from both grid-side converter (GSC) and rotor-side converter (RSC), as shown in Fig. 1, cause a large second-order harmonic current in the dc capacitors as well as voltage ripples in the dc link. It results in higher power loss in the dc capacitors and higher operating temperature, which will speed up evaporation of the electrolytes liquid and shorten their lifespan. Further, low-frequency ripple current is more detrimental than high frequency. The control of dc voltage used in the GSC for the PMSG is slightly different to the grid-connected converters under the unbalanced conditions, because the dc-voltage ripples are caused not only by the unbalanced grid voltage but also by the active power fluctuations from the RSC. In order to obtain constant dc voltage, the GSC should reject these two disturbances, i.e., the unbalanced grid voltage and the RSC fluctuating active power.

A **permanent magnet synchronous generator** is a generator where the excitation field is provided by a permanent magnet instead of a coil.

Synchronous generators are the majority source of commercial electrical energy. They are commonly used to convert the mechanical power output of steam turbines, gas turbines, reciprocating engines, hydro turbines and wind turbines into electrical power for the grid.

In the majority of designs the rotating assembly in the center of the generator—the "rotor"—contains the magnet, and the "stator" is the stationary armature that is electrically connected to a load. A set of three conductors make up the armature winding in standard utility equipment, constituting three phases of a power circuit—that correspond to the three wires we are accustomed to see on transmission lines. The phases are wound such that they are 120 degrees apart spatially on the stator, providing for a uniform force or torque on the generator rotor. The uniformity of the torque arises because the magnetic fields resulting from the induced currents in the three conductors of the armature winding combine spatially in such a way as to resemble the magnetic field of a single, rotating magnet. This stator magnetic field or "stator field" appears as a steady rotating field and spins at the same frequency as the rotor when the rotor contains a single dipole magnetic field. The two fields move in "synchronicity" and maintain a fixed position relative to each other as they spin.

In a permanent magnet generator, the magnetic field of the rotor is produced by permanent magnets. Other types of generator use electromagnets to produce a magnetic field in a rotor winding. The direct current in the rotor field winding is fed through a slip-ring assembly or provided by a brushless exciter on the same shaft. Permanent magnet generators do not require a DC supply for the excitation circuit, nor do they have slip rings and contact brushes. However, large permanent magnets are costly which restricts the economic rating of the machine. The flux density of high performance permanent magnets is limited. The air gap flux is not controllable, so the voltage of the machine cannot be easily regulated. A persistent magnetic field imposes safety issues during assembly, field service or repair. High performance permanent magnets, themselves, have structural and thermal issues.

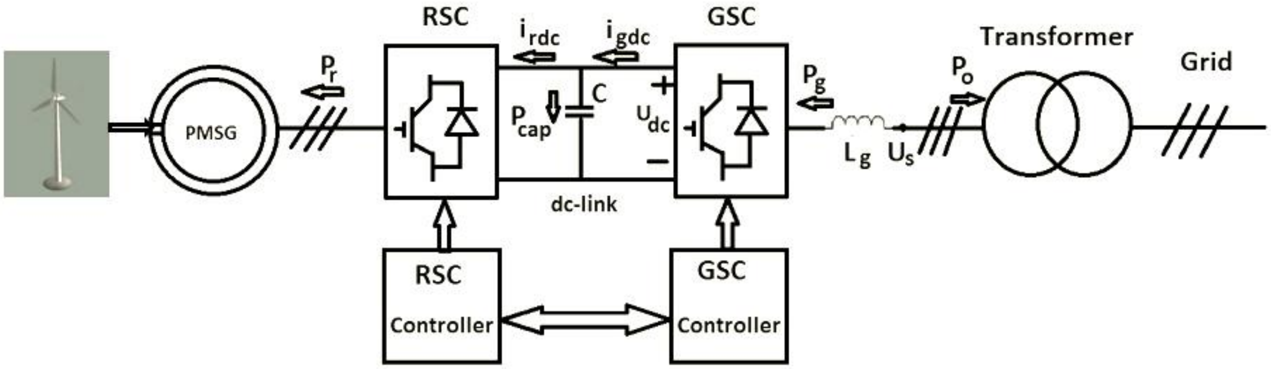

Fig 2 Circuit Diagram Of Proposed System

V. VARIOUS CONTROL TECHNIQUES

Several control techniques have been presented for the GSC controller to reduce the voltage ripple during the voltage unbalance, which can be divided into three categories: 1) feed-forward methods; 2) dual current control methods; and 3) resonant controller methods.

The feed-forward methods include a grid voltage feed forward control and an RSC dc-current (i.e., a load current for GSC) feed-forward control. The impact of the grid voltage unbalance on the dc capacitors is reduced by the grid voltage feed-forward control, and the impact of the RSC active power fluctuations on the dc capacitors is reduced by the RSC dc-current feed-forward control. However, the control delay may degrade the control performance of the feed forward methods, and the feed-forward terms may also include high-frequency noise. Moreover, in order to detect the RSC dc current, additional hardware of the load current detection may be needed.

To avoid additional detection circuits, an alternative approach is that the GSC controller calculates the real-time RSC active power based on the rotor current and rotor voltage reference. This requires that the GSC controller and the RSC controller should be integrated into one controller, which loses the modularity of the converters. It is worth noting that large-scale converters usually have a modular structure for higher reliability and maintenance.

Dual current control is a popular method for regulating the positive-sequence current and negative-sequence current at the same time. The positive and negative current references are calculated from the desired powers and the grid voltages. Multiple control targets are available by setting of the references, such as constant stator power, balanced stator currents, constant electromagnetic torque, and constant dc voltage. Under the unbalance conditions, to obtain constant dc voltage, the output fluctuating active power of the GSC must be equal to that of the RSC. Then, the current references of the GSC depend on the fluctuating active power of the RSC. As a result, this method cannot be implemented in wind power converters with a modular structure.

Since the frequency of the dc-voltage ripple is twice of the grid frequency, a resonant controller is added to the original dc voltage controller to increase the dc-voltage loop gain exactly at twice the grid frequency. By doing so, the control loop gain is large enough to reject the disturbances. Then, a constant dc voltage is obtained. However, the added resonant controller may reduce the phase margin of the system when the resonant frequency is close to or below the crossover frequency of the dc-voltage loop due to a phase step change of 180◦ around the resonant frequency. Since the bandwidth of the dc-voltage outer loop is normally lower than 100 Hz for large-scale DFIG converters, whose switching frequency is typically around 2–3 kHz, the resonant controller used in a dc-voltage controller is not a good option for converters when considering system stability. Moreover, the dynamic of the outer loop is slow. In order to make the dc capacitors more reliable under unbalanced conditions, this paper is focused on the second-order dc-capacitor harmonic current elimination by using a robust and modular control method for the GSC. First, negative impacts of the unbalanced grid voltage on the dc capacitors are discussed. Then, a dc-capacitor current control method with a negative sequence resonant controller is proposed to reduce the impact and implemented in the grid-voltage - oriented *dq*-frame.

VI.RESULTS AND DISCUSSION

The PMSG based wind turbine is modelled and simulated using MATLAB. The results shows the minimization of large second order harmonics and voltage fluctuation.

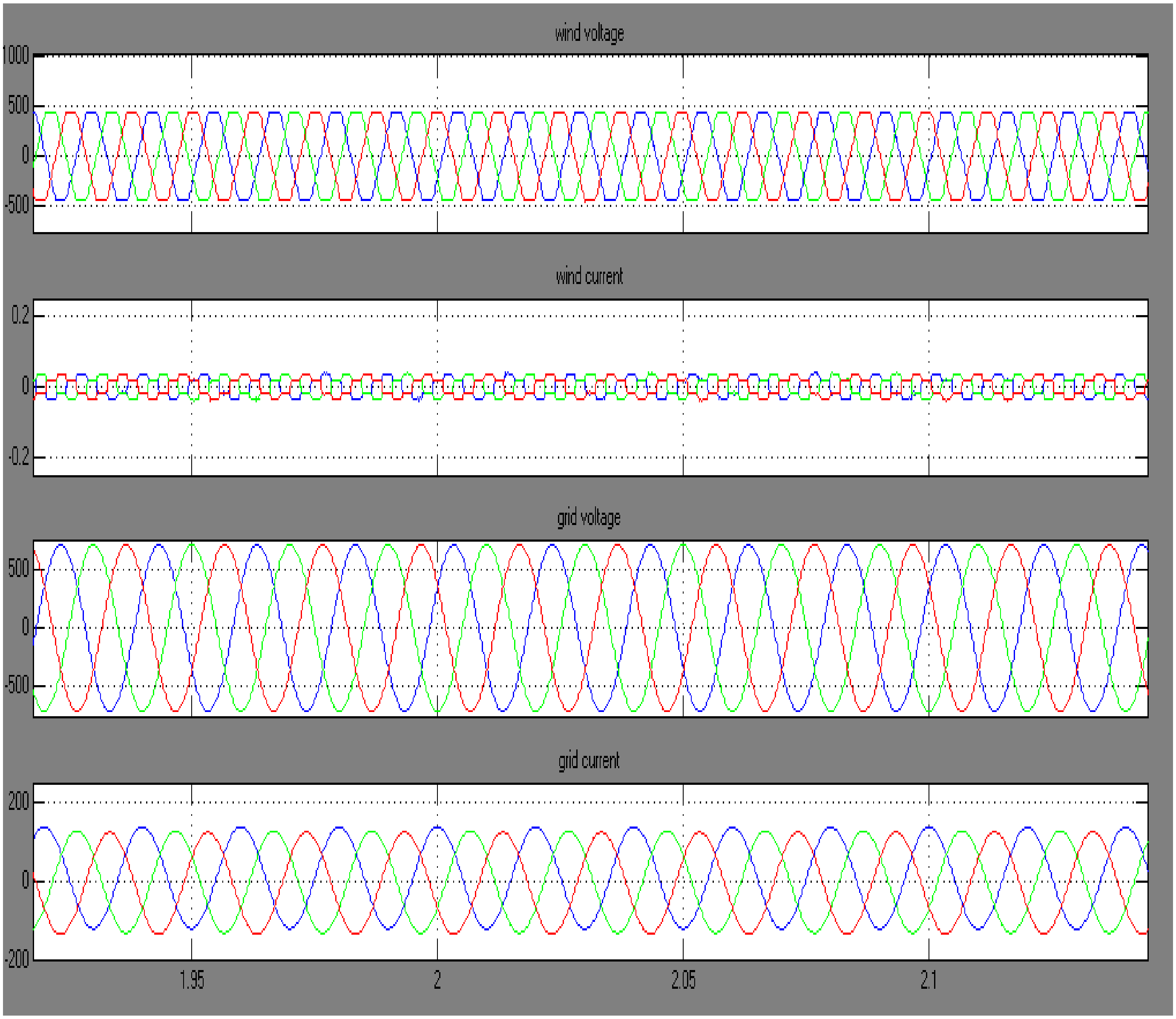

Fig 3 Output of Grid Voltage and Current

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VII.CONCLUSION

In order to reduce the negative impact of the second-order harmonic current in the dc capacitor and thereby increase the reliability of the dc-link capacitors of the PMSG converters, this project proposes a dc-capacitor current control method for a GSC. The dc-capacitor current is obtained by means of detecting the dc voltage fluctuation, so it does not require any additional hardware detection, which also contributes to the cost saving in the method. The proposed dc-capacitor current control algorithm is implemented in the GSC controller without any power information from the RSC controller. Therefore, the GSC controller can be independent of the RSC controller by using the proposed control method. This makes the control method more suitable for large-scale PMSG converters with a modular structure. Furthermore, the proposed control method has very little impact on the system stability. The experimental results show that the second order dc-capacitor current is eliminated and also the dc-voltage fluctuation is suppressed. Hence, the dc capacitors will be more reliable under unbalanced grid voltage conditions. The experimental results also show that the dc-capacitor current control method is robust to the measuring deviation of the dc-capacitor current.

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