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New switching technique for current control of grid converters for wind power systems

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ABSTRACT

A novel modification is applied to the hysteresis band (HB) modulation technique for direct current control in Grid side converters (GSC). This method employs a pair of hysteresis bands (a positive one and a negative one) and changes these bands according to the conduction times of the inverter switches. The rate of change of generated current is dependent on two factors: the instantaneous grid voltage and the conduction times of the inverter switches. The objective of changing the hysteresis bands is varying the switching frequency to reduce the ripple produced in grid currents. The proposed method is analyzed and tested in switching a voltage source grid connected converter applied in wind power systems. The matlab based simulations and experimental results validate efficacy of the new switching modulation method in decreasing the current ripple, switching losses, and Total harmonic distortion (THD) of Grid current.

1. Introduction

Wind energy is playing an increasingly important role in the supply of energy of most industrialized countries, and its share of the electrical generation is expected to continue to increase for many years to come. The EUs target for 2020 is a 20% share of energy from renewable sources; it is assumed that a high percentage of the expected growth will be from wind power [1]. Recent findings suggest that the share of 20% may even be exceeded at least in some regions [2].

Nowadays, DFIG are most commonly used by the wind turbine systems especially for larger wind turbines. The most effective reason for the popularity of DFIG is the relatively small size of power converters – almost 10%–30% of rated turbine power – which is a cost efficient solution in order to get a variable speed system [3,4]. As the wind power generation is integrated into the grid, the influence of wind turbines on the grid power quality is becoming an important matter, and this effect depends on the quality of generated current by the wind energy conversions systems. The DFIG stator is directly connected to the grid, and its rotor is connected to the grid through back to back converters systems (machine side converter and grid side converter coupled by a DC capacitor link). The control algorithm and the switching techniques of the two converters play an important role in the performance quality of DFIG. The machine side converter is responsible for speed control and Grid side converter is responsible for power exchange with the grid according to the speed operation mode of machine side converter.

The performance requirements of Grid Connected Converters (GCC) are hardly met by digital controls slowed down by conversion delays and calculation times. Fast transients and low current-ripples content call for wide-band controls. To obtain high accuracy and to compensate for the voltage disturbances a high loop gain must be adopted. However, a safe stability margin must be ensured too.

The above requirements conflict with each other. The performance can be improved by increasing the switching frequency. However, as in GCC, the power involved is quite high and the available switching components do not allow too high frequencies to be adopted. Moreover, as the switching frequency increases, the effects of the dead times increase as well, which add to the voltages disturbances mentioned above.

The quality of the current waveform generated by a Grid Connected converter relays basically on three factors: (i) The reference current; (ii) the switching technique and (iii) the switching frequency of the PWM modulator [5].

Generally, the current control algorithm of a VSC can be classified into two types: (1) direct tracking error control through PWM and (2) indirect current control where the current error is fed to a controller to generate the converter voltage command [6–10].

The direct current error control methods, such as hysteresis control, synchronized on–off control, and ramp comparison. These

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methods are very simple to be implemented and have good current regulation dynamics. The switching frequency variation is the main drawback of these methods. There are some techniques are used for maintaining constant switching frequency, such as generating a flexible hysteresis band by using a phase-locked loop, feeding back the max current error, detecting zero crossing of current, feeding forward the current error slope. These methods are complex and lead to worse dynamic performance [11]. However, the average current control accuracy with this method is low to some extent, and only the maximum switching frequency can be determined. The ramp-comparator PWM compares the current error with a triangular carrier waveform to generate the switching pulses with a fixed switching frequency. However, this method may lead to output current amplitude and phase errors [12].

In this paper, a new modulation technique is proposed. The new technique keeps all the advantages of the hysteresis technique. This method is applied for driving pulses of GSC for doubly fed induction generator driven by wind turbine system.

The main scope of this work is studying the effect switching technique of Grid side converters on the quality of the current generated to/drawn from the electrical network. So, the control algorithm and performance results of the machine side converters used for speed control and power tracking are out the scope of this paper.

The proposed switching technique can be applied for any grid connected renewable energy sources, such as solar power systems, permanent magnet synchronous generator driven by wind turbine, and DFIG driven by wind turbine. The acknowledgment of increasing installed capacity of grid connected with DFIG is the motivation for testing the proposed method on Grid side converters of DFIG systems.

2. The doubly fed induction generator

Induction generators are increasingly used these days because of their relative advantageous features over conventional synchronous generators. These features are brushless and rugged construction, low cost, maintenance and operational simplicity, self-protection against faults, good dynamic response, and capability to generate power at varying speed. The later feature facilitates the induction generator operation in stand-alone/isolated mode to supply far flung and remote areas where extension of grid is not economically viable.

Indeed, amongst many variable speed concepts, WECS using doubly-fed induction generators have many advantages over others. For example, the power converter in such wind turbines only deals with rotor power, therefore the converter rating can be kept fairly low, approximately 20% of the total machine power. This configuration allows for variable speed operation while remaining more economical than a series configuration with a fully rated converter. Other features such as the controllability of reactive power help doubly-fed induction generators play a similar role to that of synchronous generators. For these reasons DFIG based WECS is a cost efficient solution in order to get a variable speed system.

The doubly fed induction generator (DFIG) shown in Fig. 1 is a kind of induction machine in which both the stator windings and the rotor windings are connected to the source. DFIG and synchronous machines are currently the most two competing solutions in variable-speed wind turbine. A DFIG used in wind turbines offers different advantages as operation at variable rotor speed, generation of electrical power at lower wind speeds, and control of the power factor. Wind power is controlled by coupling the rotor of the DFIG to the grid through two back-to-back converters which called Grid side converter (GSC) and rotor side converter (RSC). GSC controls network side of the back to back

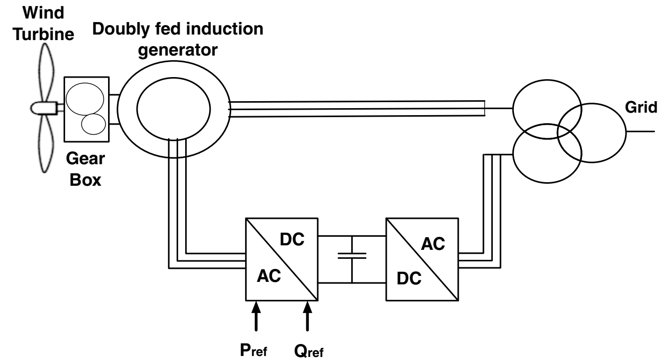

Fig. 1. Doubly fed induction generator system.

converters net active and reactive power production by controlling net current. Then, RSC controls electrical torque, stator active power, and stator reactive power production by controlling rotor current and RSC output voltage. Rotor active power will be equal to net GSC active power and dc link capacitor power by maintaining the dc link capacitor voltage constant when ignoring the power losses of power electronic devices. In the back-to-back PWM converter of DFIG, the bidirectional power is transferred between the grid side and the rotor side. Under a constant dc-link voltage, the input power from the grid side should be equal to the input power to the generator rotor.

Let us consider the mechanical power of the turbine at the exit from a gearbox Pmech (for simplicity the losses in the generator are neglected) is by means of rotating magnetic field converted into electric power Pg, which is delivered to the power grid, and the slip power in the rotor $\mathrm{Pr} = -\mathrm{sPg}$. This can be shown using expression $\mathrm{Pg} = \mathrm{Pmech} + \mathrm{sPg}$.

The rotor slip s is defined as the difference between the speed of the rotating stator field and the rotor speed $s = (ns - n)/ns$ and in the generating mode it is always negative. In generating mode the sign of power Pr will be positive (into the grid), and since the slip s is positive for motoring mode, the power Pr in the motoring mode will be negative (from the grid). For the usual range of turbine speed regulation, from 70% to 110% of the rated speed, and the synchronous speed of the generator of around 90% of the rated speed of the turbine, the slip is in the range ±23%, and the required power of the converter in the rotor is around 30% of the power which is electromechanically converted in the machine.

3. GSC control scheme

In this paper, a simple control is used to maintain constant average DC bus voltage at its reference value. A PI controller is used also to regulate the DC bus voltage to its reference value and compensates for the inverter losses. A low pass filter is used to clean up the ripples in the measured signal path of the DC bus voltage. The filtering of DC voltage ensures that power flow between the DC bus of the inverter and Grid takes place only at fundamental frequency. To achieve unity power factor, the output of the PI controller is multiplied by a three phase sinusoidal signals which are synchronized with the grid voltage. These reference current signals ensure active power exchange with the grid according to the requirements of speed control system which is achieved by RSC, as shown in the Fig. 2.

The PWM switching pulses for the IGBTs in GSC are generated by direct current control using hysteresis current modulator over reference Grid currents ($i^*_{\mathrm{Ga}}, i^*_{\mathrm{Gb}}, i^*_{\mathrm{Gc}}$) and measured Grid currents ($i_{\mathrm{Ga}}, i_{\mathrm{Gb}}, i_{\mathrm{Gc}}$).