Synchronization of DFIG output voltage to utility grid in wind power system

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ABSTRACT

This paper presents a new synchronization algorithm for grid connection of a doubly fed induction generator (DFIG) in a variable speed wind generation system. Stator flux-oriented vector control for back-to-back PWM converters in the DFIG rotor circuit is used for synchronization process. By controlling the rotor *d*-axis current, the magnitude of the stator EMF is adjusted to be equal to the grid voltage. PLL circuit is used to compensate for the phase shift between the stator EMF and the grid voltage. By controlling the turbine pitch angle, the generator speed is determined to adjust the stator frequency to be equal to the grid. The experimental results show a smooth synchronization and fast dynamic responses. Compared to the existing DFIG synchronization algorithms, the proposed method gives fast starting and can take only 2 cycles to be performed and has satisfactory performance and better robustness than existing methods.

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1. Introduction

It is well known that wind power generation using a variable speed constant frequency (VSCF) scheme produces electricity over a wide range of wind speeds, thus having a high energy capture capability. One commonly used VSCF scheme employs a doubly fed wound-rotor induction generator using an ac/dc/ac PWM converter in the rotor circuit [l,2]. The DFIG can supply power at constant voltage and constant frequency while the rotor speed varies. This makes the DFIG suitable for variable speed wind power generation. The main advantages of this system are the decoupled control of active and reactive power and the reduced rating of power converter (25–30%). The DFIG using back-to-back PWM converters for the rotor circuit has been well established in wind generation applications. When used with a wind turbine, it offers several advantages compared with fixed speed generators. These advantages, including speed control and reduced flicker, are primarily achieved by controlling the voltage-source converter, with its inherent four-quadrant active and reactive power capabilities [3–6].

As shown in Fig. 1, the stator of the DFIG is connected through SW 3 to the balanced three-phase grid and the rotor side is fed via the back-to-back IGBT voltage-source converters with a common dc bus. The ac–dc converter controls the power-flow between the dc bus and the rotor side and allows the system to be operated in sub-synchronous or super synchronous speed. The active power is generated based on the wind speed value and wind turbine characteristics while the reactive power command is determined as a function of the desired reactive power converter compensation. The vector control strategy of the power converter is based on the stator flux-oriented control which allows a decoupled control of generator torque and rotor excitation current. The control system makes it possible to improve dynamic behavior of the wind turbine, resulting in the reduction of the drive train stress and electrical power fluctuations, and increasing energy capture [7].

The DFIG operation and control have been intensively investigated so far [8–10]. On the other hand, only a few papers have handled the DFIG control during the synchronization process. There are two control schemes for DFIG synchronization published. One method is based on direct torque control (DTC) [7], and the other is based on the field oriented control (FOC) [11]. These methods are very simple, however, null current connection without an impact to the grid and the machine is not guaranteed. As a result, inrush current may go high depending on the degree of failure in the process of synchronization.

In this paper an induced stator voltage equal to the grid voltage is generated before the synchronization by adjusting the rotor flux. This procedure performs a null current connection with a very low impact to the grid and the machine. The paper describes soft and fast synchronization of the DFIG to the grid as well as independent control of active and reactive power of the generator using the stator flux-oriented vector control at normal operation. During the generator synchronization process, the turbine pitch angle controller adjusts the speed close to the synchronous speed to

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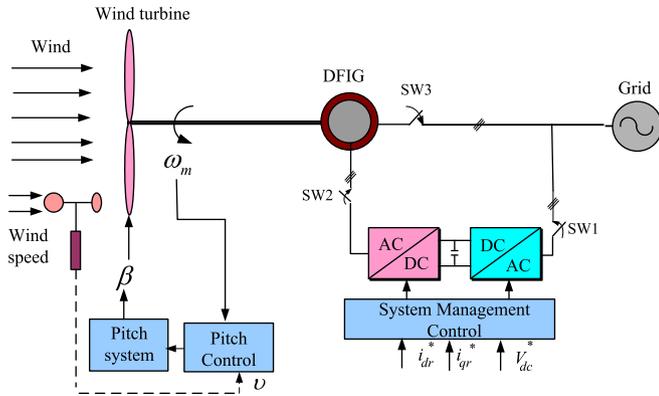 E-mail address: a_galal@aun.edu.eg.

Fig. 1. Basic configuration of DFIG wind turbine.

make sure that the stator frequency is the same as that of the grid. The magnitude of stator EMF is controlled by adjusting the rotor flux and the phase shift between the stator and grid voltages is compensated by PLL circuit. The effectiveness of the proposed algorithm is verified and demonstrated by the experimental results.

2. DFIG synchronization control

2.1. Normal operation control

Fig. 2 shows the schematic of the DFIG wind turbine configuration and its control scheme. The stator of the DFIG is connected to the utility grid. The back-to-back PWM converter in the rotor side provide a bi-directional power-flow control thereby enabling the DFIG to operate either in sub-synchronous ($\omega_r < \omega_s$) or in

super synchronous modes ($\omega_r > \omega_s$). In both modes the stator active power is generated from the DFIG and delivered to the grid. On the other hand, the rotor active power is either supplied to the machine in the sub-synchronous mode or delivered to the grid in the super synchronous mode. The stator active power is controlled directly assuming that a maximum generator developed power is known from the optimum generator speed value. The operating curve of the studied wind turbine, which is applied to most modern wind turbines [12], is illustrated in Fig. 3. This curve is characterized by four sections as follows; A ∼ B for rotor speed which is less than the minimum angular speed for optimum operation, B ∼ C for an optimal characteristic curve given by $P_{\mathrm{opt}} = K_{\mathrm{opt}}v^3$ (where v is the wind speed) in between the cut-in speed and the rated speed, C ∼ D for a constant speed characteristic up to the rated power, and D ∼ E for a constant power characteristic beyond the speed limit followed by a blade pitch control action for high wind speed.

The reference stator power P^* of the DFIG is used as the reference value for the power control loop. In the inner current control loop, the stator flux vector position is used to establish a reference frame that allows q-axis components of the rotor current to be controlled. As the reference rotor current components are in stator flux-oriented coordinates, these must be transferred to the same reference frame as the DFIG rotor current vector. This is achieved by rotating the rotor reference current vector by an angular position θ_{sl}. Due to the rotor speed variation, θ_{sl} is updated at every sample interval. Once the reference frame for both the reference and measured current vectors are conformed, simple proportional plus integral (PI) regulators can be used to control the d- and q-components of the rotor current.

Adjustment of the q-axis component of the rotor current controls either the generator developed-torque or the stator-side active power of the DFIG.
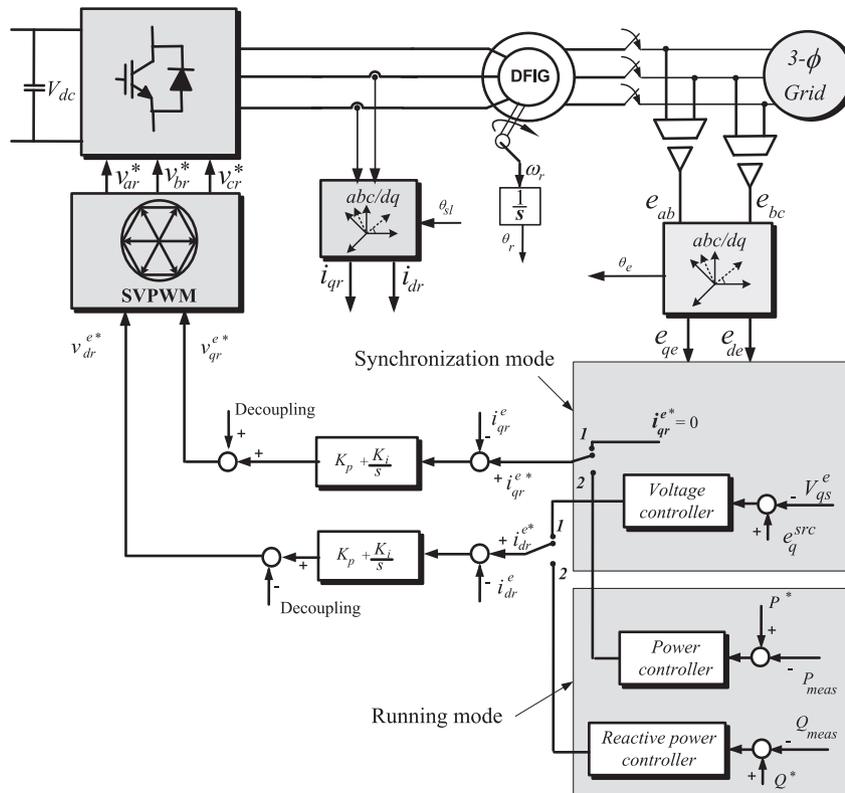

Fig. 2. Active and reactive power control for synchronization mode and running mode.