October 2012

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Recommended Citation

Pattnaik, Manasi (2012) "Study of DOUBLY-FED Induction Generator For Variable Speed Wind Energy Conversion Systems," *International Journal of Power System Operation and Energy Management*. Vol. 1 : Iss. 4 , Article 9.

DOI: 10.47893/IJPSOEM.2012.1045

Available at: <https://www.interscience.in/ijpsoem/vol1/iss4/9>

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Study of DOUBLY-FED Induction Generator For Variable Speed Wind Energy Conversion Systems

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Abstract - In recent years, wind energy has become one of the most important and promising sources of renewable energy, which demands additional transmission capacity and better means of maintaining system reliability. The evolution of technology related to wind systems industry led to the development of a generation of variable speed wind turbines that present many advantages compared to the fixed speed wind turbines. For example, grid codes are being revised to ensure that wind turbines would contribute to the control of voltage and frequency and also to stay connected to the host network following a disturbance. In response to the new grid code requirements, several DFIG models have been suggested recently. This paper deals with the introduction of DFIG and AC/DC/AC converter control

I. INTRODUCTION

The conventional energy sources are limited and have pollution to the environment. So more attention and interest have been paid to the utilization of renewable energy sources such as wind energy, fuel cell and solar energy etc. Wind energy is the fastest growing and most promising renewable energy source among them because it is abundant, cheap, inexhaustible, widely distributed, clean, and climate-benign, a set of attributes that no other energy source can match. In India, the total installed capacity of wind power generation is 8754 MW in the year 2008. By the end of 2012, the total installed capacity is going to be reached to 12000 MW according to ministry of new and renewable energy. turbine generators (WTGs) can be divided into two basic categories : (i) fixed speed and (ii) variable speed. The fixed-speed generator has a low efficiency of wind power conversion and no ability to provide reactive power support. It also imposes mechanical stress on the turbine and requires complex pitch control to maintain a constant rotor speed [2]. During the last few years, the variable speed wind turbines with Doubly-fed induction generator (DFIG) dominant the wind energy conversion system (WECS) [3]. There are several reasons for using variable-speed DFIG based wind turbines; among those are (i) Possibilities to reduce stresses of the mechanical structure, (ii) Acoustic noise reduction and (iii) The possibility to control active and reactive power [4]-[5]. In DFIG the power processed by the power converter is

only a fraction of the total wind turbine power, and therefore its size, cost and losses are small.

II. DOUBLY FED INDUCTION GENERATOR

Fig. 1 : Doubly fed induction generator with converters

Where V_r is the rotor voltage and V_{gc} is grid side voltage. The AC/DC/AC converter is basically a PWM converter which uses sinusoidal PWM technique to reduce the harmonics present in the wind turbine driven DFIG system. Here C_{rotor} is rotor side converter and C_{grid} is grid side converter. (Fig.1) shows a WECS system with doubly-fed induction generator (DFIG), which is a standard, wound rotor induction machine with its stator windings directly connected to the grid and its rotor windings connected to the grid through an AC/DC/AC frequency converter (Fig.1). This kind of machine has to be fed from both the rotor and stator sides [6]. The frequency converter is built by two self-

commutated PWM converters, a rotor-side converter and a grid-side converter, with an intermediate DC voltage link [7]. By controlling the converters on both sides, the DFIG characteristics can be adjusted so as to achieve maximum of effective power conversion or capturing capability for a wind turbine and to control its power generation with less voltage/power fluctuation. Many control algorithms have been proposed and used for controlling the DFIG rotor- and grid-side converters for certain dynamic and transient performance achievements of DFIGs [8-11]. The rotor-side converter controls the active and reactive power of the DFIG independently, and the grid-side converter controls DC-link capacitor voltage in a set value and maintains the converter operation with a desired power factor.

III. OPERATING PRINCIPLE OF DFIG

Fig. 2- Power flow diagram of DFIG

The stator is directly connected to the AC mains, whilst the rotor is fed from the Power Electronics Converter via slip rings to allow DFIG to operate at a variety of speeds in response to changing wind speed. Indeed, the basic concept is to interpose a frequency converter between the variable frequency induction generator and fixed frequency grid. The DC capacitor linking stator- and rotor-side converters allows the storage of power from induction generator for further generation. To achieve full control of grid current, the DC-link voltage must be boosted to a level higher than the amplitude of grid line-to-line voltage. The slip power can flow in both directions, i.e. to the rotor from the supply and from supply to the rotor and hence the speed of the machine can be controlled from either rotor- or stator-side converter in both super and sub-synchronous speed ranges. As a result, the machine can be controlled as a generator or a motor in both super and sub-synchronous operating modes realizing four operating modes. Below the synchronous speed in the motoring mode and above the synchronous speed in the generating mode, rotor-side converter operates as a rectifier and stator-side converter as an inverter, where slip power is returned to the stator. Below the synchronous speed in the generating mode and above the synchronous speed in the motoring mode, rotor-side converter operates as an inverter and stator side

converter as a rectifier, where slip power is supplied to the rotor. At the synchronous speed, slip power is taken from supply to excite the rotor windings and in this case machine behaves as a synchronous machine.

$$P_r = -SP_s, \text{ Where } S = W_s - W_r / W_s$$

Generally the absolute value of slip is much lower than 1 and, consequently, P_r is only a fraction of P_s . Since T_m is positive for power generation and since ω_s is positive and constant for a constant frequency grid voltage, the sign of P_r is a function of the slip sign. P_r is positive for negative slip (speed greater than synchronous speed) and it is negative for positive slip (speed lower than synchronous speed). For supersynchronous speed operation, P_r is transmitted to DC bus capacitor and tends to rise the DC voltage. For sub-synchronous speed operation, P_r is taken out of DC bus capacitor and tends to decrease the DC voltage. C_{grid} is used to generate or absorb the power P_{gc} in order to keep the DC voltage constant. In steady-state for a lossless AC/DC/AC converter P_{gc} is equal to P_r and the speed of the wind turbine is determined by the power P_r absorbed or generated by C_{rotor} . The phase-sequence of the AC voltage generated by C_{rotor} is positive for sub-synchronous speed and negative for supersynchronous speed. The frequency of this voltage is equal to the product of the grid frequency and the absolute value of the slip. C_{rotor} and C_{grid} have the capability for generating or absorbing reactive power and could be used to control the reactive power or the voltage at the grid terminals.

IV. CONVERTER CONTROL SYSTEM

The back to back PWM converter has two converters, one is connected to rotor side and another is connected to grid side. Control by both converters has been discussed here

V. ROTOR SIDE CONVERTER CONTROL SYS

The rotor-side converter is used to control the wind turbine output power and the voltage measured at the grid terminals. The power is controlled in order to follow a pre-defined power-speed characteristic, named tracking characteristic. This characteristic is illustrated by the ABCD curve superimposed to the mechanical power characteristics of the turbine obtained at different wind speeds. The actual speed of the turbine ω_r is measured and the corresponding mechanical power of the tracking characteristic is used as the reference power for the power control loop. The tracking characteristic is defined by four points: A, B, C and D. From zero speed to speed of point A the reference power is zero. Between point A and point B the tracking characteristic is a straight line. Between point B and point C the tracking characteristic is the locus of the maximum power of the

turbine (maxima of the turbine power vs turbine speed curves). The tracking characteristic is a straight line from point C and point D. The power at point D is one

per unit. Beyond point D the reference power is a constant equal to one per unit.

Fig-4 : Rotor converter control block diagram

.For the rotor-side controller the d-axis of the rotating reference frame used for d-q transformation is aligned with air-gap flux. The actual electrical output power, measured at the grid terminals of the wind turbine, is added to the total power losses (mechanical and electrical) and is compared with the reference power obtained from the tracking characteristic. A Proportional-Integral (PI) regulator is used to reduce the power error to zero. The output of this regulator is the reference rotor current I_{qr_ref} that must be injected in the rotor by converter C_{rotor} . This is the current component that produces the electromagnetic torque T_{em} . The actual I_{qr} component is compared to I_{qr_ref} and the error is reduced to zero by a current regulator (PI). The output of this current controller is the voltage V_{qr} generated by C_{rotor} . The current regulator is assisted by feed forward terms which predict V_{qr} . The voltage at grid terminals is controlled by the reactive power generated or absorbed by the converter C_{rotor} . The reactive power is exchanged between C_{rotor} and the grid, through the generator. In the exchange process the generator absorbs reactive power to supply its mutual and leakage inductances. The excess of reactive power is sent to the grid or to C_{rotor} .

V-I characteristics of turbine

The wind turbine control implements the V-I characteristic illustrated in Fig. As long as the reactive current stays within the maximum current values ($-I_{max}$, I_{max}) imposed by the converter rating, the voltage is regulated at the reference voltage V_{ref} . A voltage drop is used for the V-I characteristic shown in Fig. (3% at maximum reactive power output).

When the wind turbine is operated in var regulation mode the reactive power at grid terminals is kept

constant by a var regulator. The output of the voltage regulator or the var regulator is the reference d-axis current I_{dr_ref} that must be injected in the rotor by converter C_{rotor} . The same current regulator as for the power control is used to regulate the actual I_{dr} component of positive-sequence current to its reference value. The output of this regulator is the d-axis voltage V_{dr} generated by C_{rotor} . The current regulator is assisted by feed forward terms which predict V_{dr} . V_{dr} and V_{qr} are respectively the d-axis and q-axis of the voltage V_r .

VI. GRID SIDE CONVERTER CONTROL SYSTEM

The Grid side converter is used to regulate the voltage of the DC bus capacitor. For the grid-side controller the d-axis of the rotating reference frame used for d-q transformation is aligned with the positive sequence of grid voltage. This controller consists of :

Grid side converter control

1. A measurement system measuring the d and q components of AC currents to be controlled as well as the DC voltage V_{dc} .
2. An outer regulation loop consisting of a DC voltage Regulator.
3. An inner current regulation loop consisting of a current Regulator.

The current regulator controls the magnitude and phase of the voltage generated by converter C_{grid} (V_{gc}) from the I_{dgc_ref} produced by the DC voltage regulator and specified I_{q_ref} reference. The current regulator is assisted by feed forward terms which predict the C_{grid} output voltage.

VII. CONCLUSION

Description about DFIG and AC/DC/AC converter control have been outlined in this paper. With increased penetration of wind power into electrical grids, DFIG wind turbines are largely deployed due to their variable speed feature and hence influencing system dynamics.

This has created an interest in developing suitable models for DFIG to be integrated into power system studies. The continuous trend of having high penetration of wind power, in recent years, has made it necessary to introduce new practices.

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