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Modeling of Three Phase Ac-Ac Matrix Converter on Dfig Based Wind Energy Conversion System

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ABSTRACT

This paper presents a full description of three phase AC-AC matrix converter modeling through the wind energy conversion system (WECS) based on double fed induction generator (DFIG).MC is a proposed drive system used to perform the AC-AC conversion directly without any dc link. So, it may increases the output of the power generation. It controls the MPPT by adjusting the DFIG terminal frequency and the shaft speed. In addition, the MC controls the grid injected current to be in phase with the grid voltage for the unity power factor. Space vector modulation (SVM) is used to generate the pulse width modulation (PWM) signals of the matrix converter switches. Simulation studies of the proposed power generation system were carried out. Results obtained are presented and modeled with good control performance of the system.

Keywords: Wind Energy Conversion System (WECS); Double Feed Induction Generator (DFIG); Matrix Converter (MC); Space Vector Modulation(SVM); Pulse Width Modulation (PWM);Maximum Power Point Tracking .

I. INTRODUCTION

EARTH's fossil energy resources such as oil, gas and coal are limited in production and are expected to use beyond their peak in the next decades, so the price of energy can continue to rise. Ever rising need of energy in future can met by contributing more renewable energy sources. The growing need for electrical energy and they will to preserve the nature justifies the use of renewable energy sources. The use of renewable sources for

Electric power generation has been a huge increase since the past decade. Increased economical and ecological woes have driven researchers to discover newer and better means of generating electrical energy. In this race, the production of electricity by wind turbine is actually the best method in comparison with the energy produced by the solar source conversion and this is due to the price per a kilo watt that is less elevated with respect to the second [1].

Among the most used and available technologies for wind turbines, the doubly fed induction generator (DFIG) is the most accepted because it presents greater benefits for a reduced conversion structure and efficient energy capture due to the variable speed operation of wind turbine based on a conversion (DFIG). The doubly fed induction generator is the most popular option for harnessing energy from the wind because of variable and unpredictable nature of the wind speed. This base structure (DFIG) offers the benefits of improved efficiency, reduced converter, cost and losses are reduced, easy implementation of power factor correction, a variable speed operation, and the control four quadrants of active and reactive power.

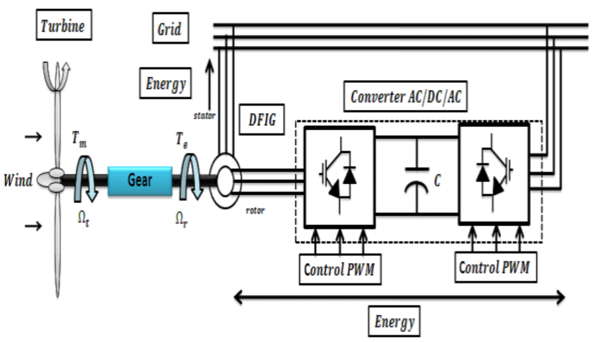

Figure 1. Wind Energy Conversion System's structure

Due to variable speed operation, the total energy production is 20% to 30% higher and therefore capacity utilization factor is improved and the cost per kWh of energy is reduced. In general, the stator windings of the DFIG are directly connected the electrical network and the rotor windings are powered via bidirectional PWM voltage converters (VSC). The control strategy is used to control the rotor and the stator output power supplied to the grid variable speed operation [2]. Decoupled control of active and reactive powers is the used approach based on vector control. Transfer of active power by a wind turbine based on (DFIG) in the distribution network can be carried out by the stator and rotor. The transfer direction of the active power is determined by wind speed and hence the synchronous speed of the generator. When a speed of the generator below the synchronous speed then the transfer of active power flows from the network to the electric rotor machine. The transfer is made by two cascaded converters. The first is linked to the network operates as a rectifier and the second operates as an inverter is connected to the rotor of the generator.

However, an AC-DC-AC converter system requires large DC-link capacitors, making the system bulky and expensive. In addition, its control scheme employs two current-regulated PWM controllers, one for the supply-side converter, the other the generator-side converter [3]. The control algorithms are thus complicated, having potentially a reliability problem. A direct AC-AC matrix converter can offer all the advantages given by its AC-DC-AC counterpart [4, 5]. More importantly it converts AC power in a single stage and eliminates large energy storage components. The work described in talus paper is based on a simulation study of a matrix converter controlled DFIG for wind power generation. For maximum energy capture from the wind, high performance speed control is desired to enable the speed of the generator to track closely the value predicted by the wind turbine power-speed characteristic curve. This is realized by regulating the rotor current using a stator flux, field-oriented scheme and a space-vector modulated matrix converter. The control scheme also enables flexible adjustment of the power factor. The principle of using the space vector modulation technique to control the matrix converter in a closed loop configuration is discussed.

In this paper, the use of a direct matrix converter [5, 6, and 7] for the control of the rotor-side currents of a DFIG system is proposed. Such a configuration offers certain advantages, notably:

1) The power converter requires no bulky an costly energy storage components, like those in the dc-link converter,
2) The control scheme required by a direct AC-AC conversion scheme is simpler than that used by a two-stage power conversion.

For maximum energy capture from the wind, high performance speed control **is** desired to enable the generator speed to closely track the value predicted by the wind turbine power-speed characteristic curve. This is realized by regulating the rotor current using a stator-flux, field-oriented scheme and a space-vector modulated matrix converter. The control scheme also enables flexible adjustment of the power factor. In this paper, the operating principles of this power generation scheme and the control method used are discussed. Simulation studies were carried out using a 7.5kW induction generator. The results under various operating conditions are presented. Features of the system and its modeling performance are scrutinized. The Wind energy conversion system configuration used in this work (DFIG with converters cascade and a capacity energy storage system in the dc link) is shown in Figure 1.

II. DOUBLY FED INDUCTION GENERATORS (DFIG)

The doubly fed induction generators (DFIG) are wound rotor induction generator. The DFIG is based on the concept, which corresponds to a variable speed wind turbine configuration with a wound rotor induction generator (WRIG) and a partial-scale power electronic converter on the rotor circuit, as illustrated. The stator is directly connected to the grid, whereas the rotor is connected through a back to back power electronic converter. The power converter controls the rotor frequency and thus the rotor speed. This concept supports a wide speed range operation, depending on the size of the frequency converter. Typically, the variable speed range is ±30% around the synchronous speed. The rating of the power electronic converter is only 25–30% of the generator capacity, which makes this concept attractive and popular from an economic point of view [3].

There are various advantages of DFIG reported as its controllability of both active and reactive power is better. The large rotor inertia smoothest the variations of wind speed and as a result it has fewer fluctuations in output power. The most important advantage of DFIG is its ability to get ride through fault by its uninterruptable operation. DFIGs connect to grid with selecting a good control; it has uninterruptable operation and can successfully ride through grid faults. The uninterruptable operation can be achieved by properly arranging the operation and control of the converters and using dynamic reactive compensation [4].

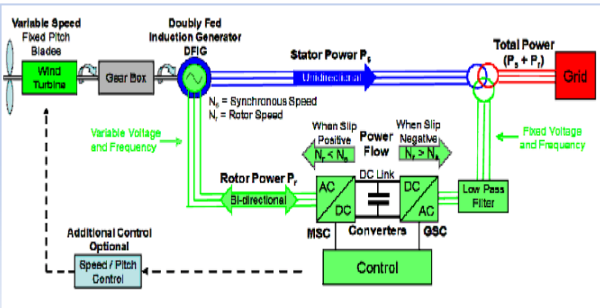

Figure 2. Power flow diagram of DFIG

The stator is directly connected to the AC mains, whilst the wound rotor is fed from the Power Electronics Converter via slip rings to allow DIFG to operate at a muddle 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. [4] To achieve full control of grid current, the DC-link voltage must be boosted to a level 18 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 [3, 4].

The mechanical power and the stator electric power output are computed as follows:

$P_r = T_m * W_r$ & $P_s = T_{em} * W_s$

For a loss less generator the mechanical equation in steady-state at fixed speed for a loss less generator

$T_m = T_{sm}$ and $P_m = P_s + P_r$

where,

S $(W_s - W_r)/W_s$ is defined as the slip of the generator

Generally, the absolute value of slip is much lower than 1 and, consequently, Pr is only a fraction of Ps. Since Tm is positive for power generation and since ωs is positive and constant for a constant frequency grid voltage, the sign of Pr is a function of the slip sign. Pr is positive for negative slip (speed greater than synchronous speed) and it is negative for positive slip (speed lower than synchronous speed). For super-synchronous speed operation, Pr is transmitted to DC bus capacitor and tends to raise the DC voltage. For sub-synchronous speed operation, Pr is taken out of DC bus capacitor and tends to decrease the DC voltage. Cgrid is used to generate or absorb the power Pgc in order to keep the DC voltage constant. In steady-state for a lossless AC/DC/AC converter Pgc is equal to Pr and the speed of the wind turbine is determined by the power Pr absorbed or generated by Crotor. The phase-sequence of the AC voltage generated by Crotor is positive for sub-synchronous speed and negative for super-synchronous 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.

III. MATRIX CONVERTER CONTROLLED DFIG

The matrix converter is a forced commutated converter which uses an array of controlled bidirectional switches as the main power elements to create a variable output voltage system with unrestricted frequency. It does not have any dc-link circuit and does not need any large energy storage elements.

A. System Configuration

In the generation system, an AC-AC matrix converter may be used to supply the variable-frequency voltages to the rotor terminals of the induction machine. Figure 3 shows schematics of the matrix converter-DFIG configuration and its simplified control scheme. The stator of the generator is connected directly to the utility grid. A matrix converter is inserted in the rotor circuit, giving direct AC-AC power conversion between the rotor circuit and grid.

The grid-side connection is made via a three-phase LC filter to suppress high-order harmonics. A matrix converter provides bidirectional power-flow control thereby enabling the DFIG to operate in either sub synchronous (or<ws) or super synchronous modes (w,>o,). 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. Now the output power of a wind turbine at a specific wind speed varies with change of the turbine shaft speed.

The control objective is to ensure that the power developed by the turbine is a maximum at any wind speed. The control scheme must also maintain continuous power flow from the DFIG to the grid.[6]. To achieve this, a turbine shaft speed which results in a maximum turbine power must be determined and the DFIG is controlled so as to obtain the desired shaft speed. The desired shaft speed can be determined by an optimal power tracking algorithm which is not fully investigated in this present work.

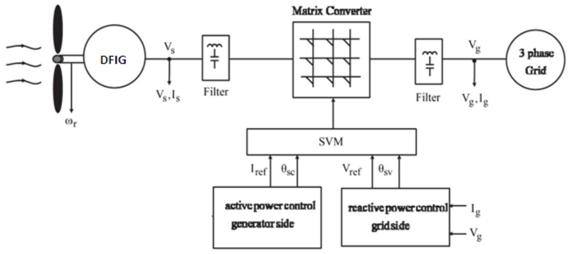

Figure 3. Conventional Matrix Converter in WECS

Instead, the stator active power is controlled directly assuming that a maximum generator developed power is known. The ideal machine stator power, denoted by P_s is used as the reference value for the DFIG power control loop. In the inner current control loop, the stator-flux vector position is used to establish a reference frame that allows the d and q axis components of the rotor current to be controlled independently. Adjustment of the q-axis component of the rotor current. i_{qr} controls either the generator developed-torque or the stator-side active power of the DFIG *(Ps)*.Regulating the d-axis component, *jdr,* controls directly the stator-side reactive power flow *(Qs).*

B. Principle of Active and Reactive Power Control

To provide independent control of the stator active power P, and reactive power Qs of the DFIG, by means of rotor current regulation, it is necessary to define the dq components of the rotor currents in the stator-flux oriented reference frame and show that P, and Q, can be represented as functions of the individual current components. Subsequently, the P, and Qs commands can be used to determine the reference rotor currents. Stator-flux oriented control is used to regulate the rotor current. In this scheme the d components of the rotor current vector is aligned with the stator-flux linkage vector λ_s, hence the active and reactive currents supplied to the power grid become linear functions of the rotor current d and q components, given as

$i_{qs}^{e} = \frac{Lm}{Ls} i_{qr}^{e}$ and $i_{ds}^{e} = \frac{Lm}{Ls}(\lfloor i_{ms}^{s} \rfloor - i_{ds}^{e}$ (1)

The magnitude of the stator magnetizing current vector i_{ms} is a constant determined by the supply voltage. The stator active and reactive power components may be given as

$$P_s = \frac{3}{2}\, V_{ds}^{e}\ i_{ds}^{e} + V_{qs}^{e}\, i_{qs}^{e}\ = \frac{3}{2}\, V_{ds}^{e}\ i_{ds}^{e}$$

$$= -\frac{3}{2}\ W_e \frac{Lm}{Ls}\, i_{ms}^{e}\, i_{qr}^{2} \qquad (2)$$

$$Q_s = \frac{3}{2}\, V_{qs}^{e}\ i_{ds}^{e} + V_{ds}^{e}\, i_{qs}^{e}\ = \frac{3}{2}\, V_{qs}^{e}\ i_{ds}^{e}$$

$$= -\frac{3}{2}\ W_e \frac{Lm}{Ls}\, i_{ms}^{e}\, i_{dr}^{2} \qquad (3)$$

Knowing L_{ms} , Ls, and ideal values of p_s^e and Q_s^e, the reference values for i_{dr}^e and j_{ds}^e can be calculated directly from the above equations.

C. Space Vector Modulation Control of the Matrix Converter

Once the input and output voltage values are specified for each sampling period, the space vector modulation (SVM) method can be directly applied to control the matrix converter[5,6,]. The method represents the three-phase input currents and output line-to-line voltages as space vectors. It is based on the concept of approximating a rotating reference voltage vector with those phased realizable on a matrix converter. For nine bidirectional switches, there are 27 valid switch combinations which may be divided into *5* groups [6,8].

The first group consists of six vectors whose angular positions vary with the change of input voltage vector. This group of vectors is not employed in the SVM method. The next three groups of switch combinations have two common features, namely, each of them consists of six vectors which all hold constant angular positions and each of them defines a six sextant hexagon. These, so named stationary vectors, are used to synthesize the desired output voltage vector. The remaining group comprising three zero vectors is also used in the method. The modulation process consists of two procedures: vector selection and vector on-time duration calculation. At a given time instant T , the SVM method selects 4 stationary vectors to approximate a desired reference voltage with the constraint of unity input power factor.

To achieve this. the amplitude and phase angle of the reference rotor voltage vector are calculated and the desired phase angle of the input current vector is determined in advance. The stationary vectors chosen should be adjacent to the sextant where the reference voltage vector locates. Moreover their magnitudes are equivalent to the maximum line-to-line input voltage at the given sampling instant. It is performed at every sampling interval. Note that the maximum achievable output voltage is limited to 86% of the input voltage due to the fact that the peak-to-peak output voltage cannot be greater than the minimum line-to-line input voltage. However, this restriction may not be a significant drawback for this application.

IV. SIMULATION AND RESULTS

A 10 MW wind farm consisting of five wind turbines each of 2 MW connected with a 25 kV distribution system. This grid-tie wind turbine model based on DFIG and three-phase-to-three-phase matrix interface converter has been carried out in Matlab/Simulink environment. The complete Simulink model is shown in figure 4.

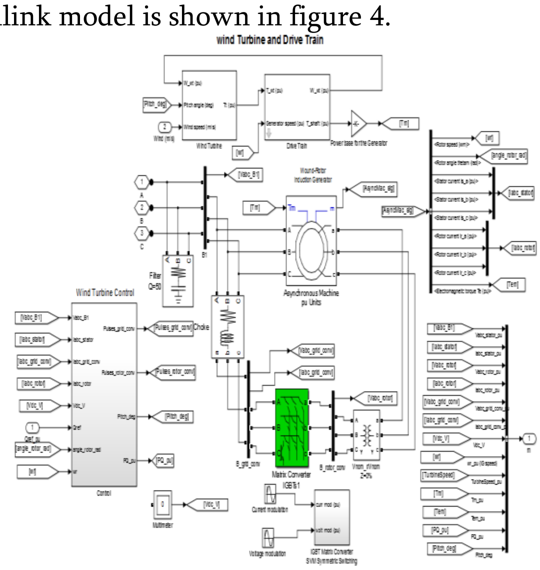

Figure 4. Complete simulink model of wind turbine with Matrix converter

This system consists of a three-phase matrix converter (MC) constructed from 9 back-to-back IGBT switches. The MC is supplied by an ideal 60Hz three-phase source and drives a static resistive load at 60Hz. The switching algorithm is based on an indirect space-vector modulation. Indirect space-vector modulation allows direct control of input current and output voltage and hence allows the power factor of the source to be controlled. The switching algorithm utilizes a symmetric switching sequence. LC filters are also included in this model so that the output waveforms can be seen clearly.

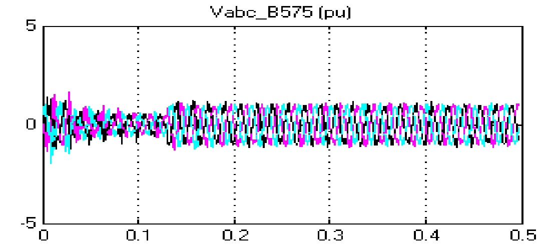

Figure 5 Voltage waveform of Grid connected to wind energy system

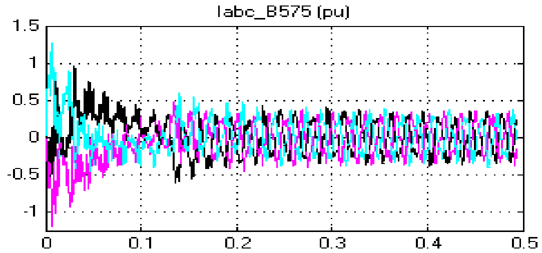

Figure 6. Current waveform of Grid connected to wind energy system

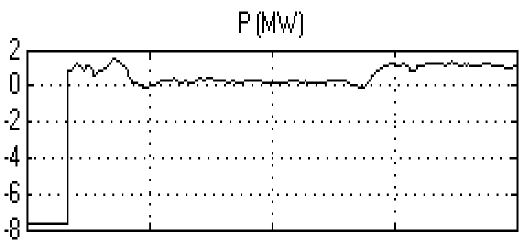

Figure 7. Active power of wind turbine

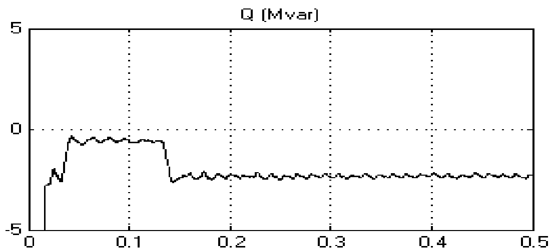

Figure 8. Reactive power of wind turbine

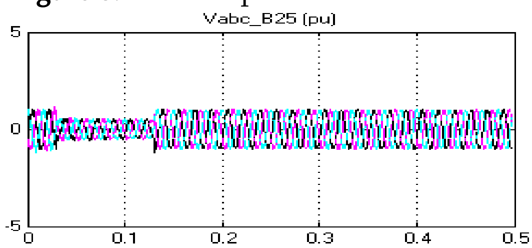

Figure 9. Voltage waveform of wind turbine

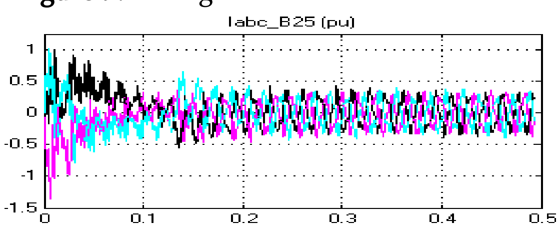

Figure 10. Current waveform of wind turbine

DIFFERENT WIND SPEED

Table 1

Wind Speed (M/Sec)	Line to Line Voltage (volts)	Frequeny (Hz)	Rotor Speed (rad/sec)	Active Power (kW)	Reactive Power (kVAR)
7	245	38.5	105	5.4	140
9	312	43.2	130	6.95	180
12	390	50	152	8.5	270
14	438	55.8	174	10.8	420
16	487	62.2	205	14.28	580

V. CONCLUSION

This paper presented a wind generation system employing in the model of MC and DFIGURE When the speed increases, both frequency and amplitude of the output voltage from the DFIG also increases. In order to obtain the constant output voltage with constant frequency, the synchronous generator is coupled with the matrix converter. A controlled rectifier rectifies the output voltage of DFIG and rectified output is given to the inverter. As there is no DC link element between the converter and the inverter, the converter produces the constant DC voltage irrespective of wind velocities. The constant DC voltage from the converter is given to the input of inverter to obtain an AC output voltage of constant amplitude with constant frequency. There by constant output voltage with constant frequency is obtained from the proposed Wind Energy Conversion Scheme. The MC, controlled by SVM, enables excellent transient response while sinusoidal current waveforms are dominant with grid currents in-phase with the grid voltage for unity power factor.

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