Matrix Converter Technology for Renewable Energy Systems in Doubly-Fed Induction Generators

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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. These wind energy conversion systems are connected to the grid through Voltage Source Converters (VSC) to make variable speed operation possible. The studied system here is a variable speed wind generation system based on Doubly Fed Induction Generator (DFIG). The Matrix Converter has several advantages over traditional rectifier-inverter type power frequency converters. It provides sinusoidal input and output waveforms, with minimal higher order harmonics and no subharmonics; it has inherent bi-directional energy flow capability; the input power factor can be fully controlled. The proposed converter is capable of direct ac/ac power conversion and, except for a few smalls number elements; it does not require the use of any input inductors or a dc-link capacitor. Here DFIG introduction and AC-AC converter control and finally the SIMULINK/MATLAB simulation for Matrix Converters as well as for grid connected doubly Fed Induction Generator and corresponding waveforms are discussed.

Index Terms—Matrix Converter, Doubly fed Induction Generator, Sinusoidal Pulse Width Modulation.

I. INTRODUCTION

Withincreased penetration of wind power into electrical grids, DFIG wind turbines are largely deployed due to their variable speed feature and hence influencing system dynamics. DFIGs are widely used for variable speed generation and they are the most important generators for wind energy applications. For a typical DFIG, the power converters are connected to the rotor and, for restricted speed range, regulate a large fraction of the ungenerated power, typically 30% of nominal power. In conventional implementation of grid-connected DFIG, back-to-back converters are used to connect the DFIG to the utility. The rotorside converter controls the magnetizing and torque currents. The grid side converter regulates the voltage in the dc-bus. The back-to-back converters. In this paper, a new topology is proposed. The back-to-back converters are replaced by a Matrix Converter. The Matrix Converter provides bidirectional power flow, sinusoidal input/output currents, and controllable input power factor. When compared to back-to-back converters, the Matrix Converter has some significant advantages. For instance, due to the absence of electrolytic capacitors, the Matrix Converter can potentially be robust and reliable. The space saved by an Matrix Converter, compared to an conventional back-to-back converter, has been estimated as a factor of three. Therefore, in some applications, the Matrix Converter can be embedded in the machine itself. Furthermore, there is no intrinsic limitation to the Matrix Converter power. A sinusoidal pulse width modulation (SPWM) technique is used to control the Matrix Converter, regulating the rotor torque and magnetizing currents. Fig. 1 shows the proposed wind energy conversion system (WECS). In the Matrix Converter, input side, a second-order LC power filter is used to improve the current waveform and reduce the input voltage distortion. The interaction between the Matrix Converter and input power filter may produce resonances and even instability in the system.

II. WIND ENERGY CONVERSION SYSTEM

The last decades have seen a significant expansion of the use of the Wind Energy Conversion System (WECS). This is due to the fact that this energy yields the production of electricity without any gas emission. There are several reasons for using variable speed operation of wind turbines. Among them, the possibility to decrease stresses of the mechanical structure and acoustic noise reduction and possibilities to control Active and Reactive power. Most of the major wind turbine manufacturers are developing new larger wind turbines in the 3-6 MW range. These allwind turbines are based on Variable wind speed operation with pitch controlling adrectified drivingsynchronization generator or a Doubly Fed Induction Generator. The major advantage of the DFIG is that the Power Electronic equipment only has a drive part of the total system power; this means that the losses in the Power Electronic converters are reduced as well as the cost.
III. DOUBLY FED INDUCTION GENERATOR

A. Introduction to DFIG

Wind turbines use a doubly-fed induction generator (DFIG) consisting of a wound rotor induction generator and an AC-AC IGBT-based Matrix Converter. The stator winding is connected directly to the 50 Hz grid while the rotor is fed at variable frequency through the AC-AC converter. The DFIG technology allows extracting maximum energy from the wind for low wind speeds by optimizing the turbine speed, while minimizing mechanical stresses on the turbine during gusts of wind. The optimum turbine speed producing maximum mechanical energy for given wind speeds is proportional to the wind speed. Another advantage of the DFIG technology is the ability for power electronic converters to generate or absorb reactive power, thus eliminating the need for installing capacitor banks as values.

B. Equivalent circuit of DFIG

The induction machine can be represented by the transformer per phase equivalent circuit model where \( R_r \) and \( X_r \) represent rotor resistance and reactance referred to the stator side. The primary internal stator induced voltage \( E_s \) is coupled to the secondary rotor induced voltage \( E_r \) by an ideal transformer with an effective turn ratio \( a_{eff} \). But the equivalent circuit differs from the transformer equivalent circuit primarily in the effects of varying rotor frequency on the rotor voltage \( E_r \). In the case of doubly fed induction machines, however, there is a voltage injected into the rotor windings so that the normal induction machine equivalent circuit needs to be modified by adding a rotor injected voltage in the stator and rotor voltage and current respectively.

C. Mathematical model of DFIG

From the equivalent circuit for a doubly fed induction machine, the real and reactive power of stator \( P_s, Q_s \) and rotor \( P_r, Q_r \) and the torque developed \( T_m \) can be derived as follow.
\[ P_{SW} = 3V1I1 \cos(\phi V1 - \phi I1), \]
\[ P_{sq} = 3V1I1 \sin(\phi V1 - \phi I1), \]
\[ P_{rW} = 3V2I2 \cos(\phi V2 - \phi I2), \]
\[ P_{rq} = 3V2I2 \sin(\phi V2 - \phi I2), \]
\[ T = 3EsiIr \cos(\phi Esr - \phi I2). \]

IV. MATRIX CONVERTER

The Matrix Converter is an array of bidirectional switches as the main power elements, which interconnects directly the power supply to the load, without using any dc-link or large energy storage elements. The most important characteristics of matrix converters are: 1) simple and compact power circuit; 2) generation of load voltage with arbitrary amplitude and frequency; 3) sinusoidal input and output currents; 4) operation with unity power factor; 5) regeneration capability. These highly attractive characteristics are the reason for the tremendous interest in this topology.

V. SINGLE PHASE MATRIX CONVERTER

![Single Phase Matrix Converter Topology](image1)

![Bi-directional Switch](image2)
The SPMC requires 4 bi-directional switches each capable of conducting current in both directions, blocking forward and reverse direction. The IGBT were used due to its popularity amongst researchers that could lead to high power applications with reasonably fast switching frequency for fine control. The circuit is arranged such that any output lines of the converter can be connected to any input lines. i denotes input, while o denotes output.

\[ V_i(t) = \sqrt{2}V_i \sin \omega t \]
\[ V_o(t) = \sqrt{2}V_o \sin \omega t \]
\[ V_o(t) = R_\text{i}o(t) + L_\text{i}o(t)/dt \]

VI. SINUSOIDAL PULSE WIDTH MODULATION

The Sinusoidal Pulse Width Modulation (SPWM) is a well-known wave shaping technique in power electronics. For realisation, a high-frequency triangular carrier signal, \( V_c \), is compared with a sinusoidal reference signal, \( V_r \), of the desired frequency. The crossover points are used to determine the switching instants. The frequency of the output voltage depends on the reference signal frequency. The magnitude ratio of the reference signal \( V_r \) to that of the triangular signal \( V_c \) is

![Fig 5: Formation of SPWM](image-url)
VII. MAIN MODEL OF SPMC IN MATLAB/SIMULINK

Fig 6: SPMC in MATLAB/SIMULINK

VIII. BI-DIRECTIONAL SWITCH MODULE

Fig 7: Bi-directional switch
IX. SIMULATION RESULTS

Fig 8: SPMC with varying output frequency

a) Output voltage: Input frequency: 50Hz, Output frequency: 100Hz

b) Output current: Input frequency: 50Hz, Output frequency: 100Hz

a) Output voltage: Input voltage: 50V, Modulation Index: 0.7
b) Output Current: Input voltage: 50V, Modulation Index: 0.7, Input Frequency: 50Hz, Output Frequency: 50Hz

c) Output Current: Modulation Index: 1, Input Frequency: 50Hz
X. THREE PHASE MATRIX CONVERTER

The matrix converter is a single-stage converter, which is composed of an array of mxn bidirectional powerswitches, each connected between one phase of the input and one phase of the output. Theoretically, the number of input phases, m, must be at least three, and the number of output phases, n can be chosen from one to infinity. The basic matrix converter topology which connects a three-phase voltage source to a three-phase load is the most important converter from a practical point of view. A matrix converter is an unlimited frequency changer, which can generate both smaller and bigger output frequency than input frequency of the converter. The output voltage waveforms are constructed by piecing together selected segments of the input voltage waveforms.

Each switch is characterized by a switching function. Each switch $S_{Kj}, K=\{A,B,C\}, j=\{a,b,c\}$ can connect one phase of the input stage to one phase of the load. Output voltages $v_{j}$ can be synthesized by switching according to a proper combination of these switches. Control of the matrix converter must comply with the following basic two rules. Firstly, any two input terminals should never be connected to the same output line to prevent short-circuit, because the MC is fed by a voltage source. The other, an output phase must never be open-circuited, owing to the absence of a path for the inductive load current which leads to the over-voltages.

![Three Phase Matrix Converter topology](image)

XI. SIMULATION RESULTS

**a)** Input voltages which have 20% third and 10% fifth harmonics

**b)** Output currents without compensation
c) Output currents with compensation

d) Fig11: Three-phase output currents for MC under distorted input voltage conditions (fo = 25 Hz)

Fig 13: Three-phase output voltage for MC under distorted input voltage conditions (fo = 25 Hz)

a) Output voltage without compensation

b) Output voltage with compensation

c) Fig14: Three-phase output voltage for MC under distorted input voltage conditions (fo = 50 Hz)
XII. CONCLUSION

This paper has evaluated the performance of a Matrix Converter based DFIG WECS. Underundesirable effects of the input voltage, the proposed compensation technique is an effective method to reduce harmonics of the output current and voltage. The DFIG is able to provide a considerable contribution to grid voltage support during short circuit periods. The matrix converter replaces the use of PWM dc-link converters which reduces losses produced due to the energy storage elements. The MATLAB/ SIMULINK models of Matrix Converter results are validated.

XIII. REFERENCES


