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Model Predictive Control of Matrixconverter Fed Induction Generator for Wind Turbine

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Abstract – The conventional direct torque control scheme for induction motor drives is extended to directly control the active power delivered to the grid by a wind turbine driven induction generator. The generator is interfaced to the grid through an AC-AC matrix converter. A constant switching frequency based direct power control scheme with flux and power controllers is proposed. The space vector modulation method is used to synthesize the pulse width modulated output voltages from the matrix converter and to control the power factor of the currents on the grid side. The Model predictive controller is used for controlling the active and reactive power generated from the generator. Simulation for the same is carried out with MATLAB Simulink and the results are analyzed.

Index Terms – Induction Generator, Model Predictive Control, Space Vector Modulation (SVM).

1. INTRODUCTION

The Induction Generator has been widely used and researched in wind generator applications. The primary benefit of this system over other generator configurations is that the power electronic converters in the system need only to convert power to and from the rotor windings of the Wound Rotor Induction Machine (WRIM). This translates to a converter power rating of approximately 25% of the total generator power rating. However, these power converters in a DFIG system usually rely on a back-to-back DC link configuration to produce the AC-AC conversion. This project is an investigation into the feasibility of using a Matrix Converter (MC) to conduct the AC-AC power conversion in the rotor circuit.

The research has been based on the use of ideal switching devices in the MC. When working with the assumption of ideal switching devices many of the complexities involved with non-ideal power electronic components are not explored. Hence the viability of constructing an MC excited DFIG has not definitively established.

2. PROPOSED METHOD

In the proposed system the wind energy generation unit output is provided to the matrix converter for AC to AC conversion and the same is provide to the load. In the feedback loop the voltage and current measurements are given to the Model Predictive Controller and the PWM control for the necessary modulation activity and the details of the same is explained in chapter 3

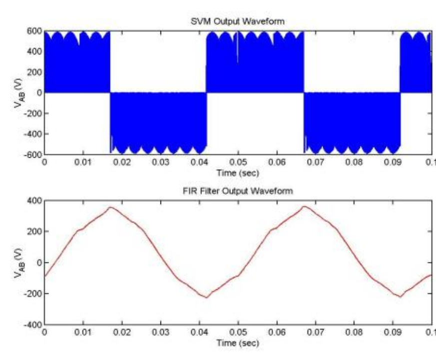
The advantages in adopting the new system is as below

- Improvement in efficiency
- Reduction of THD to below 2%.

2.1. Ideal Matrix simulation

This covers the development of a non-ideal MC model to be implemented in a DFIG system so that the viability of the system can also be analysed and assessed. Connecting a non-ideal matrix converter to a load such as a wound rotor induction machine will introduce added factors to the dynamic system and may cause the system to function incorrectly.

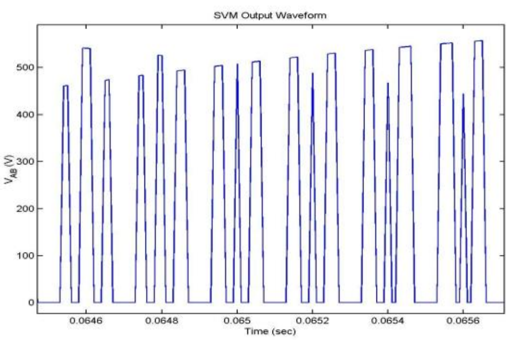
The inclusion of these quantities to the matrix converter can also impact the input filter design. Despite the incorporation of a well-designed commutation scheme, transients may be emphasized by the non-ideal nature of the system. Therefore the filter has to be designed to reduce injected frequency components.



SVM Voltage Output Obtained Using Ideal Switching Devices

As an initial assessment, the simulation of the SVM in an MC using ideal switching devices has been undertaken using MATLAB. The input of the MC is connected to a 415VL−L 50 Hz infinite busbar and the system converts the output to a synthesized 300VL−L 20 Hz waveform modulated with a switching frequency of 5kHz, as shown in Figure 4.1. A filter is used on the output signal to remove high frequency pulses and the fundamental frequency of 20 Hz can be observed. The phase shift between the filtered output and the SVM output waveforms is as a result of the FIR filter phase characteristic at 20 Hz.

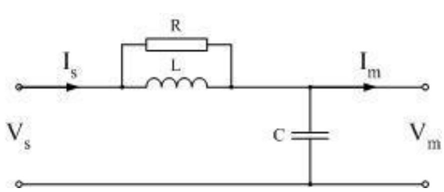
Figure below shows a zoomed view of the SVM output pulses with varying magnitudes of the output pulses. The individual output pulses are a result of the different input phases being selected by the switching combinations. This simulation shows a SVM scheme can be theoretically applied to an MC using ideal switching devices and is able to synthesize output voltage waveforms of a different voltage and frequency.



The viability of an MC in a DFIG system can be assessed by adopting non-ideal component models and using SVM theory.

2.2. Matrix Converter Filtering

To prevent high frequency switching harmonics being injected into the grid as a result of modulation, a second order Low Pass (LP) filter is applied at the input of the switching matrix. The unwanted harmonics are centredaround the switching frequency of 20 kHz which is much greater than the fundamental frequency of 50 Hz. Hence the low order harmonics are relatively small in magnitude. This means that the size of the filter may be vastly reduced. A typical LP filter used in an MC application is shown in the Figure. The resistor in the filter also adds damping to the circuit to prevent oscillations.

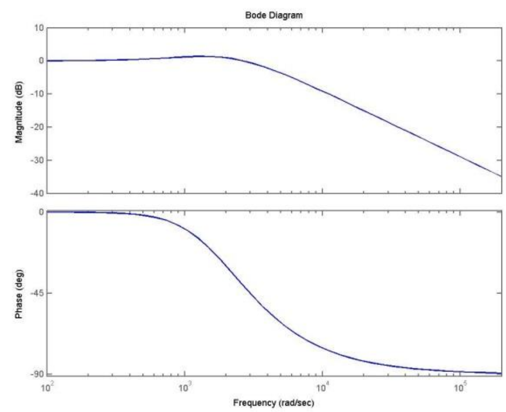


Matrix Converter Input Low Pass Filter

The transfer function of the LP filter is

$$\frac{I_s(s)}{I_m(s)} = \frac{Ls + R}{RLCs^2 + Ls + R}$$

The unwanted current harmonics are centredaround the switching frequency which is ωs = 125.67×103 rad/s, and the grid supply frequency is ωe = 314.2 6 rad/s. The filter design must remove the harmonic current components while minimizing the effect on the fundamental current component. Based on above equation the poles for the filter.the values a Bode plot can be generated which shows the relative gain (dB) versus frequency (rad/s), as shown in Figure below:



Second Low Pass Filter Bode Plot

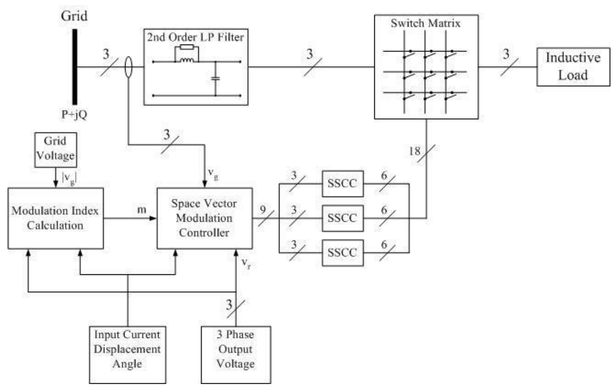
It can be seen that the filter attenuates the current at frequencies near the switching frequency and has a relatively small effect on the fundamental frequency. Also the phase change at the fundamental is relatively small. This is a desirable quality as the MC is designed such that it is able to control the input current displacement factor and any phase shift would further complicate the design process.

With these considerations, the low pass filter outlined in this section with the defined parameters is selected as the input filter for the matrix converter. The output does not require any filtering as the inductive load that the MC is connected to perform the low pass filtering of the output current waveforms.

2.3. Space Vector Modulation

The Space Vector Modulation Controller (SVMC) is designed to produce the switch combination signals at the relevant time for the nine 4QSWs of the matrix converter (MC). The SVM method that has been verified on the MC with the ideal switches is applied to a MC with non-ideal component models. The SVMC controls the 4QSWs via the semi-soft commutation controller (SSCC) which then produces eighteen gate signals to control IGBTs within the nine 4QSWs as shown below

The modulation index that is used in the SVMC is calculated by a separate block. This is done so that the modulation index can be externally controlled if needed depending on the control requirements of the system. The modulation index is calculated as a piecewise function:



Use of the piecewise function ensures that the modulation index stays within the linear voltage range of the MC. The input voltage vector magnitude used in the modulation index is determined by the input nominally rated RMS value of the grid voltage which is set at the commencement of the simulation, as indicated. This is done to ensure stability of the system during voltage transients. The SVMC applies the SVM algorithm during every switching period incorporating the following steps:

1. Read output voltage waveform values

2. Read input current waveform values

3. Calculate output voltage space vector

4. Calculate input current space vector

5. Calculate Modulation Index

6. Calculate SSV pairs

7. Calculate θiL and θoL

8. Calculate duty cycles dkm, dlm, dkn, dln and d0

9. Calculate switch times from duty cycles

10. Derive switching combinations from SSV pairs for each switch time

11. Apply switching combinations at relevant switch times

The SSCC adds latency time to the application of the switch combinations. To allow for this a time hysteresis or deadband which is set in the SVMC is added to the minimum time the controller applies a combination. This allows the SSCC to apply the gate signals effectively. If the duty time of an SSV is less than the deadband time, the SSV is not applied and the time is redistributed to the other SSVs to be applied during the switching cycle.

As there are three zero vectors, the selection of the vector that is applied depends on the dominant input phase in the previous switch combination. Every SSV combination uses no more than two input phases to generate the output three phase voltage. This means that in each SSV one of the input phases is applied to two output phases. Once the dominant input phase is determined, the zero vector that uses the same input phase is applied. This means that only one output phase connection needs to be changed. The other advantage is that if a zero vector is needed for an extended period of time, the same zero switch combination is applied. This ensures that the number of switch state changes is minimized. The input parameters of the simulation are:

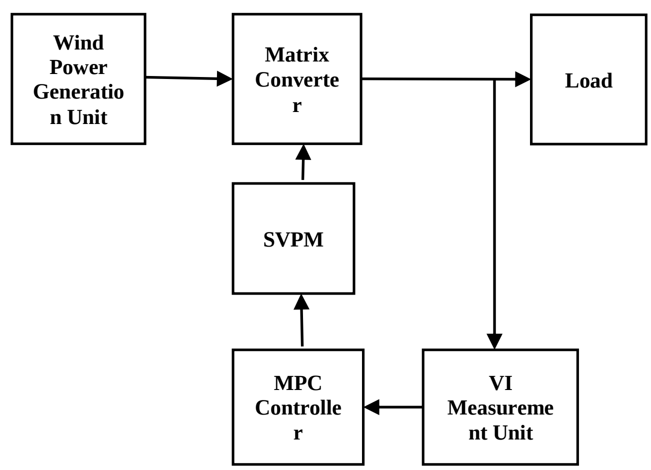
1. Switching Frequency (Hz);

2. Deadband Time (s); controls the minimum time a SSV combination is actuated.

3. Switching Cycle (Asymmetric / Symmetric); changes between Asymmetric and Symmetric switching cycle.

3. BLOCK DIAGRAM OF PROPOSED SYSTEM

The block diagram of the proposed system for reactive power control of a matrix converter fed Induction Generator is as below.



Block Diagram

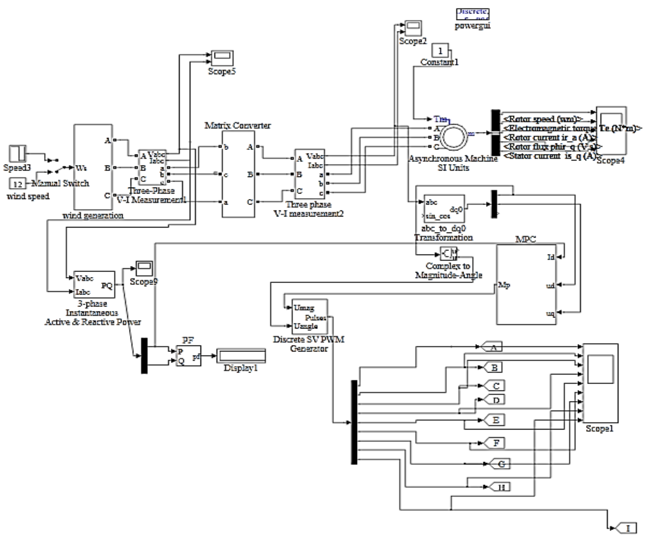
3.1. Block Diagram Description

The output from the wind generation unit is provided to the matrix converter for the conversion from AC to AC. The output is then measured for the voltage and current using the VI measurement unit. The output from the same is given to the MPC Controller and then to SVPM unit for modulation activity and then fed again to the matrix converter for controlling the active and reactive power generated from the wing power generation unit.

Model predictive control (MPC) is an advanced method of process control that has been in use in the many industries. In recent years it has also been used in power system balancing models. Model predictive controllers rely on dynamic models of the process, most often linear empirical models obtained by system identification. The main advantage of MPC is the fact that it allows the current timeslot to be optimized, while keeping future timeslots in account. This is achieved by optimizing a finite time-horizon, but only implementing the current timeslot. MPC has the ability to anticipate future events and can take control actions accordingly. PID and LQR controllers do not have this predictive ability. MPC is nearly universally implemented as a digital control, although there is research into achieving faster response times with specially designed analog circuitry.

4. SIMULATION DIAGRAM

4.1. Simulation Diagram of Matrix Fed Induction Generator

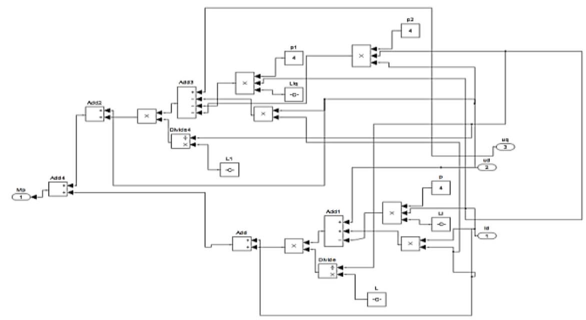


The supply generated by the wind turbine is fed in to the three phase measurement unit for measurement of voltage and current. Here the speed is calculated from the VI measurements instead of traditional speed sensor. The input from this unit is fed in to the matrix converter for necessary AC to AC conversion.

The voltage and current measurements are done again after the AC to AC at the output terminal of the matrix converter. The details from this are fed to transformation unit for signal to value conversion as this is used for the feedback process. The output from the VI measurement unit is connected to the load. The current and voltage signal from the VI measurement unit at the supply end is connected to the active and reactive power measurement unit for measurement of active and reactive power. The power factor is calculated from the active and reactive measured for necessary input to the model predictive controller. The simulation drawing of the same is provided in Figure above.

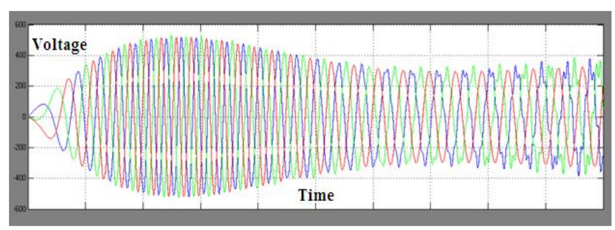
4.2. Simulation Diagram Of Model Predictive Controller Subsystem

The voltage at the point of the filter connection is considered as a disturbance and omitted by the closed loop. The closed loop consists of feedback correction and dynamic optimization. Therefore, no voltage sensors are required by the MPC controller. Hence, cost reduction is likely attained. Furthermore, calculating the control variables of the next sampling, at instant k+1, is carried out at instant k, that enables rapid tracking and fast dynamic response.

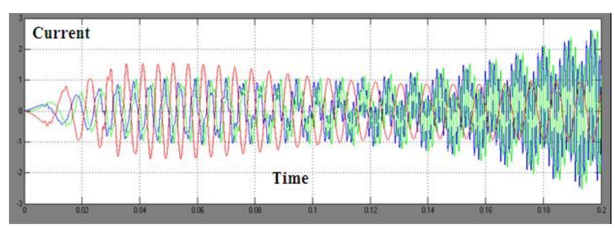


5. OUTPUT WAVEFORM

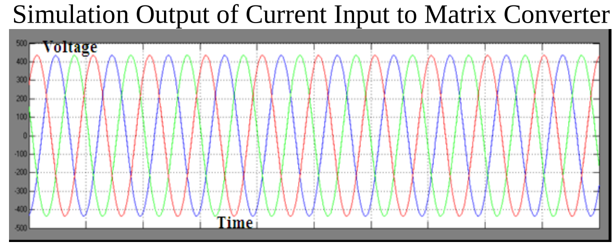
The input and the output waveforms obtained from the simulation of the matrix converter fed induction generator is shown below.



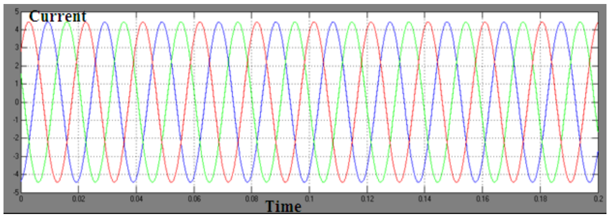
Simulation Output of Voltage Input to Matrix Converter



Simulation Output of Current Input to Matrix Converter

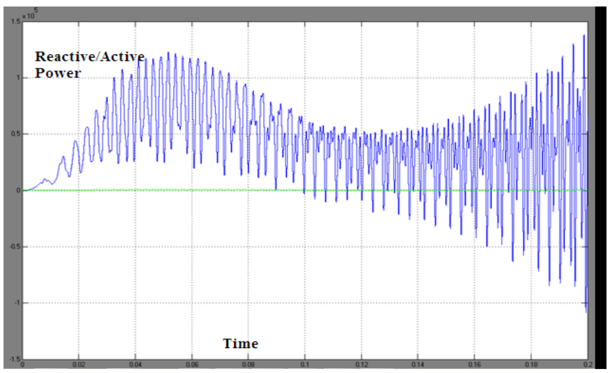


Simulation Output of Voltage Output from Matrix Converter

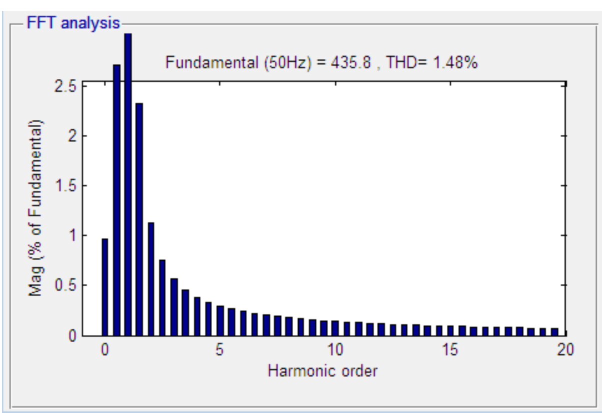


Simulation Output of Current Output from Marix Converter

The waveform of the corrected active and reactive power obtained from the use of matrix converter fed Induction Generator and model predictive controller is shown below. The waveform in yellow represents the active power generated from the wind turbine and the pink one represents the reactive power generated.



Simulation Output Active and Reactive Power



Total Harmonic Distortion

6. CONCLUSION

The principle objectives of this research was to investigate the viability of a Matrix Converter (MC) excited Induction Generator to supply decoupled active and reactive power to a utility grid. The MPC controller parameters need to be constantly adjusted in order to achieve better control performance.

A proposal has been made for reactive power control based on matrix converter. The basic concepts and operational features of the matrix converter has been explored. The investigation commenced with DFIG power flow theory and the different modes of operation (sub-synchronous and super-synchronous). Also, an investigation into WRIM theory was conducted to set the foundation for the analysis of DFIG control in the stator flux reference frame. It was shown that decoupled active and reactive power control can be achieved in a DFIG when rotor currents are regulated in the stator flux reference frame.

The proposed method is analyzed using MATLAB/SIMULINK software. From the simulation results it is clearly understand that there is improvement in reactive power control and harmonic reduction is obtained.

Simulated results are presented to demonstrate an improvement in power factor and total harmonic distortion. In conventional method power factor range is 0.88 and harmonics range of 5% and the proposed method gives the improved power factor range is 0.98 and harmonics of 1.481%.

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