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Design and Simulation of Matrix Converter for Wind Mill Applications

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Abstract **- The wind energy is considered to be one of the poor quality energies due to the variation of the velocity and direction of the wind. These variations cause fluctuations in the input power and the frequency, thereby affecting the operation of the system. At a given wind velocity, the mechanical power available from a wind turbine is a function of its shaft speed. The shaft speed is varying due to the variations in the wind velocity; thereby a varying frequency and varying voltage is developed at the output of the induction generator. Power electronics converters are used for the purpose of stabilizing the varying parameters and to obtain a constant frequency of 50Hz. Commonly used is back to back converters or AC-DC-AC converters which has a lot of disadvantages like costly, bulky. Through matrix converter, the terminal voltage and frequency of the induction generator can be controlled in such a way that the wind turbine is operating at a constant frequency of 50 Hz. PWM technique and Venturini Modulation strategy are used for the switching on and off of the switches in the matrix converter. The wind power system is analysed and simulation results are obtained by MATLAB-Simulink.**

Keywords **–** Matrix converter, frequency-voltage stabilization, MATLAB, Venturini Modulation strategy, PWM technique.

1. INTRODUCTION

The general consciousness of finite and limited sources of energy on earth, and international disputes over the environment, global safety, and the quality of life, have created an opportunity for new more efficient less polluting wind and hydro power plants with advanced technologies of control, robustness, and modularity. Due to the increasing demand on electrical energy, rapid reduction of energy sources and severe pollutions caused by fossil fuels and environmental concerns, a considerable amount of effort is being made to generate electricity from renewable sources of energy. The major advantages of using renewable sources are abundance and lack of harmful emissions. Wind is one of the most abundantly available renewable sources of energy in nature. The wind energy can be harnessed by a wind energy conversion system (WECS), composed of a wind turbine, an electric generator, a power electronic converter and the corresponding control system. In wind turbines, mechanical power of the blades is shifted to the Turbine's rotor, either directly or by use of gear boxes; and the generated energy, in most cases, is transferred to the power distribution network. Therefore the quality of produced power is in high value of importance. The quality of the produced power is mainly affected by the amplitude of the generators voltage [2-3]. In this regard, several methods have been proposed to stabilize the varying frequency. One of these methods is the use of Back to Back Converters where the alternating voltage of the turbine is converted to constant voltage using converters and then by the use of an inverter, voltage proportional to the network voltage is produced [4]. The other method used, is to sample the wind velocity and change the blades angle with respect to the variations of winds velocity. In this method the response is slow and time consuming and causes mechanical erosion of parts if used for a long period of time [5]. Other controllers find the maximum power for a given wind operation by employing an elaborate searching method [6],[7]. In another method, increasing the inertial momentum of turbine's shaft is proposed to overcome rapid fluctuations of wind [8]. In order to perform speed control of the turbine shaft, in attempt to achieve maximum power, different control methods such as field-oriented control and constant Voltage/frequency (*V/f*) have been used [8].

In this paper, a Matrix Converter is designed to stabilize the frequency variations and it is simulated and the results are analyzed. Through matrix converter, the terminal voltage and frequency of the induction generator can be controlled in such a way that the wind turbine is operating at a constant frequency of 50 Hz[9].

2. WIND ENERGY CONVERSION SYSTEM

Wind energy can be harnessed by a wind energy conversion system, composed of wind turbine blades, an electric generator, a power electronic converter and the corresponding control system. Fig.1 shows the block diagram of basic components of WECS.

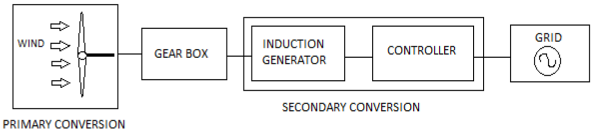

Fig.1. Block diagram of a WECS

The mathematical relationship between the wind fluctuations and the developed mechanical power is given as [10]:

$$u_t = \left(\begin{array}{l} u_0 + u_1 \sin(2\pi t/24) + u_2 \cos(2\pi t/24) + \\ u_3 \sin(4\pi t/24) + u_4 \cos(4\pi t/24) \end{array} \right) \quad -(1)$$

The mechanical power generated by a wind turbine is given as [9]

$$P = (\rho \, . \, C_p \, . \, A_r \, . \, V_w^3) / 2 \qquad -(2)$$

where,

P is the power in *W*,

P is the air density in g/m^3,

C_p is a dimensionless factor called power coefficient,

A_r is the turbine rotor area in m^2 ($A_r = \pi R_r^2$, where R_r is the rotor blade radius)

V_w is the wind speed in *m/s*.

3. EFFECTS OF WIND FLUCTUAUTIONS ON THE FREQUENCY OF THE SYSTEM

The frequency of the generator output is dependent on the shaft speed of the generator. It is given by the following relation,

$$N = 120 \, . \, f/P \qquad -(3)$$
$$f = n \, . \, P/120 \qquad -(4)$$

N → synchronous speed of the generator
f → frequency of the induced voltage
P → number of rotor poles

4. MATRIX CONVERTER

Firstly introduced in 1976, the matrix converter is a direct AC-AC converter that uses an array of m x n controlled bidirectional switches to directly connect m-phase inputs to n- phase outputs. The abilities of the bidirectional switches to conduct current in both directions and block voltage of both polarities enable a m x n phase ideal matrix converter to generate n- phase variable output with unrestricted frequency from m-phase AC supply voltages. Matrix converters are single stage converters; they need no energy storage components except small ac filters for elimination of switching ripples[11].

Fig. 2 shows the circuit configuration of a conventional matrix converter with an array of 3 x 3 bidirectional switches. Matrix converter has been extensively researched due to its potential as a replacement for the traditional AC-DC-AC converter. [12]

Compared to the traditional AC-DC-AC converter, the matrix converter offers the following benefits:[13][14][16]

- Adjustable input displacement factor
- Regeneration capability – 4 quadrant operation
- High quality input and output waveforms
- Lack of bulky and limited lifetime energy storage components such as capacitors
- Simple and compact power circuit
- Operation with unity power factor for any load

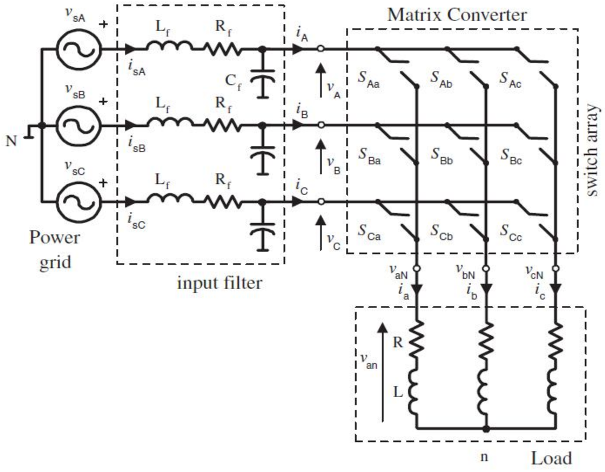

Fig.2. Matrix converter circuit topology

Filters are used at the input of the converter for 2 main reasons.[15]

- It filters the high-frequency components of the matrix converter input currents (i_A, i_B, i_C), generating almost sinusoidal source currents (i_{sA}, i_{sB}, i_{sC}).
- It avoids the generation of overvoltage produced by the fast commutation of currents i_A, i_B, i_C, due to the presence of the short-circuit reactance of any real power supply.

Matrix converter allows any input to be connected to any output line for any given time duration. Due to direct connection, the input lines must never be short circuited. If it is short circuited then infinite current flows through the switches and damages the circuit. Since the loads are mostly inductive type loads the output must never be open-circuited. If it is open circuited, infinite voltage will be across the inductor and the switches will be damaged.[15]

Switches must be controlled based on the following expression:

$$S_{jA}+S_{jb}+S_{jc}=1,\ j\ \varepsilon\ \{a, b, c\} \qquad -(5)$$

where Sjk is the switching function of a bi-directional switch, defined as:[15]

Sjk = 1 (closed)
Sjk = 0 (open)

5. MODULATION TECHNIQUES

The modulation technique used here is a combination of Venturini Modulation Strategy with PWM technique. Modulation is the procedure used to generate the appropriate firing pulses to each of the nine bidirectional switches (S_{jk}) in order to generate the desired output voltage. In this case, the primary objective of the modulation is to generate fixed-frequency and fixed-voltage sinusoidal output voltages (v_{jN}) from the variable-frequency and variable-voltage input voltages (v_i). The easiest way of doing this is to consider time windows in which the instantaneous values of the desired output voltages are sampled and the instantaneous input voltages are used to synthesize a signal whose low-frequency component is the desired output voltage.

From the Venturini Modulation Stratergy,

$$v_0(t) = M(t) \,.\, v_i(t) \qquad -(6)$$

$$i_i(t) = M^T(t) \,.\, i_0(t) \qquad -(7)$$

where,

$v_0(t)$ = low frequency output voltage vector
$v_i(t)$ = instantaneous input voltage vector
$i_i(t)$ = low frequency input current vector
$i_0(t)$ = instantaneous output current vector
$M(t)$ = low frequency transfer matrix

The modulation problem normally considered for the matrix converter can be stated as follows. Given a set of input voltages and an assumed set of output currents [14][16][17],

$$V_i = V_{im}\begin{pmatrix} \cos(W_i t) \\ \cos(W_i t + 2x\,\pi/3) \\ \cos(W_i t + 4x\,\pi/3) \end{pmatrix} \qquad -(8)$$

$$I_o = I_{om}\begin{pmatrix} \cos(W_{0.} t + \phi_0) \\ \cos(W_{0.} t + \phi_0 + 2x\,\pi/3) \\ \cos(W_{0.} t + \phi_0 + 4x\,\pi/3) \end{pmatrix} \qquad -(9)$$

The modulation matrix M(t) is calculated such that the constraint equation is satisfied. In the voltage gain between the output and input voltages,

$$V_i = q.V_{im}\begin{pmatrix} \cos(W_0.t) \\ \cos(W_0.t+2x\,\pi/3) \\ \cos(W_0.t+4x\pi/3) \end{pmatrix} \qquad -(10)$$

$$I_0 = q.\cos(\phi_0)\, I_{om}\begin{pmatrix} \cos(W_{i.} t + \phi_i) \\ \cos(W_{i.} t+\phi_i+2x\pi/3) \\ \cos(W_{i.}t+\phi_i+4x\pi/3) \end{pmatrix} -(11)$$

The first method, Venturini Modulation strategy is defined by above method. However, the calculations of the switch timings directly from these equations are complicated for practical implementations. They are more conveniently expressed directly in terms of the input voltages and the target output voltages (assuming unity displacement factor) in the form

$$M = 1/3\left\{1+(2v_i(t)\,.\,v_j(t))/V^2_i\right\} \qquad -(12)$$

For k = {A,B,C} ; j = {a,b,c}

$$M(t) = \begin{pmatrix} M_{Aa} & M_{Ba} & M_{Ca} \\ M_{Ab} & M_{Bb} & M_{Cb} \\ M_{Ac} & M_{Bc} & M_{Cc} \end{pmatrix} \qquad -(13)$$

This method is of little practical significance because the voltage ratio limitation is only about 50%. [14][17]

$$M= 1/3 \left\{ \begin{array}{l} 1+ (2V_kV_j)/V^2_{im} + \\ (4q/(3\sqrt{3}) \sin(W_t+\beta_k) \sin(3W_it) \end{array} \right\} \quad - (14)$$

For K = (A,B,C); j = (a,b,c) and β = 0, $2\pi/3$, $4\pi/3$ respectively.

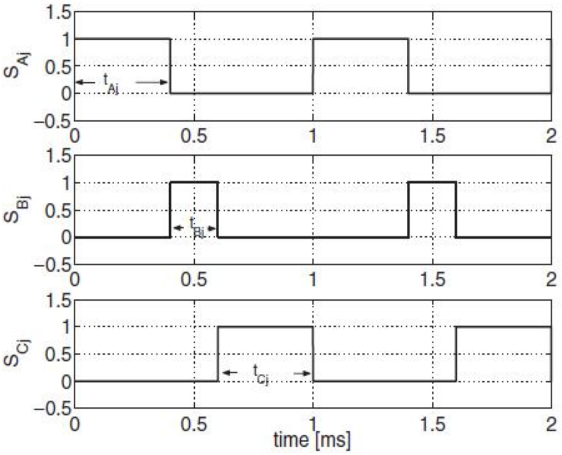

Fig.3 Switching pattern for the jth output

Fig.3 shows the switching pattern of the converter for the jth output phase. Each of the phases is given a pulse, corresponding to the time duration calculated by Venturini Modulation strategy. These pulses are generated in the duty cycle block of the Matrix Converter in fig.4. The pulses are generated with reference to the equation (12).

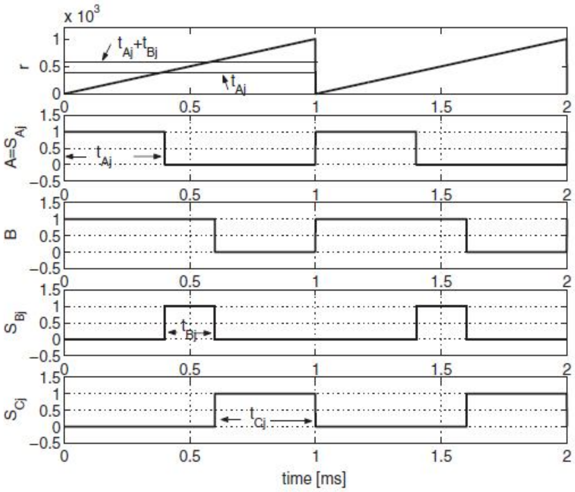

Fig.4 Variables used for the pulse generation of one output phase

Fig.4 shows the PWM Method of pulse generation for the output phases. The pulses for phases B and C are produced by the logical operation as,

S_{Bj} = not (A) and B
S_{Cj} = not (A) and not (B)

The pulses are generated for the 9 bi-directional switches and it is explained in the Table.1 given below.

TABLE 1
SWITCHING STATES OF THE SWITCHES

T \ S	S_{Aa}	S_{Ab}	S_{Ac}	S_{Ba}	S_{Bb}	S_{Bc}	S_{Ca}	S_{Cb}	S_{Cc}
T1	1	1	1	0	0	0	0	0	0
T2	1	1	0	0	0	1	0	0	0
T3	0	0	0	1	1	1	0	0	0
T4	0	0	0	1	1	0	0	0	1
T5	0	0	0	0	0	0	1	1	1
T6	1	1	1	0	0	0	0	0	0
T7	1	1	0	0	0	1	0	0	0
T8	0	0	0	1	1	1	0	0	0
T9	0	0	0	1	1	0	0	0	1
T10	0	0	0	0	0	0	1	1	1
T11	1	1	1	0	0	0	0	0	0
T12	1	1	0	0	0	1	0	0	0
T13	1	0	0	0	1	1	0	0	0
T14	0	0	0	1	1	1	0	0	0
T15	0	0	0	1	1	0	0	0	1
T16	0	0	0	1	0	0	0	1	1
T17	0	0	0	0	0	0	1	1	1
T18	1	1	1	0	0	0	0	0	0
T19	1	1	0	0	0	1	0	0	0
T20	1	0	0	0	1	1	0	0	0
T21	0	0	0	1	1	1	0	0	0
T22	0	0	0	1	1	0	0	0	1
T23	0	0	0	1	0	0	0	1	1
T24	0	0	0	0	0	0	1	1	1

6. SIMULATION

The simulation circuit of the Matrix Converter for the stabilization of frequency is shown below.

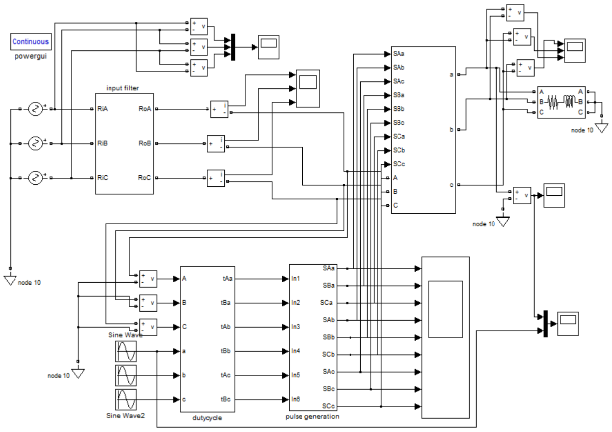

Fig.4 Simulation circuit of MC

The simulation circuit shows the input source, filter circuit, Matrix converter circuit, duty cycle circuit and the pulse generation circuit.

7. RESULTS

Fig.5 shows the output voltage of the Matrix converter along with the reference voltage.

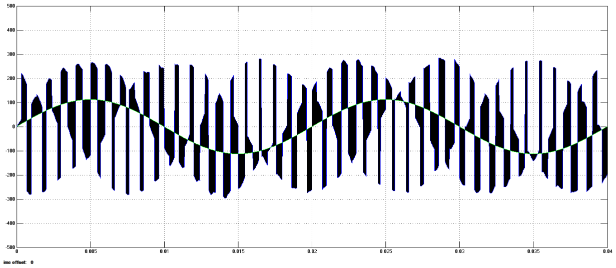

Fig.5 Output voltage and reference voltage

The results show that a constant frequency of 50 hertz is obtained from the converter circuit. The input frequency can be anywhere from 45-55 hertz whereas the output frequency is 50hertz. The voltage can also be controlled by giving the desired voltage as the reference signal.

8. CONCLUSIONS

In this paper successful simulation of a Matrix Converter has been developed in MATLAB software. The modulation technique for turning on and off of the switches in the Matrix Converter is done using Venturini Modulation strategy and PWM techniques. The output shows that frequency is stabilized and a constant 50 Hz of frequency is obtained.

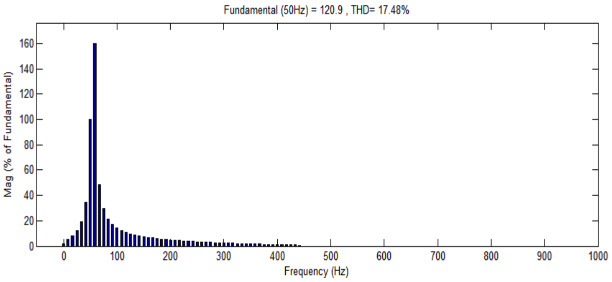

Fig.5 FFT analysis without filter

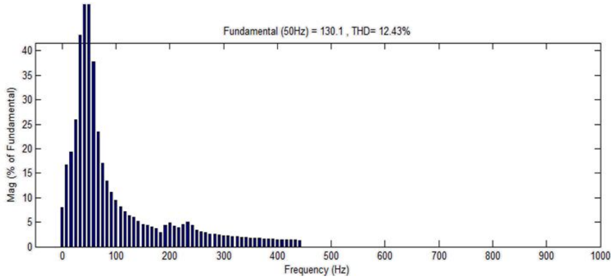

Fig.6 FFT analysis with filter

The Fast Fourier Transform analysis of the converter circuit was done and the results showed that the %THD was considerably less in the converter circuit with filter. The %THD without filter was 17.48% and with filter was 12.43%.

Thus the Matrix Converter provides a cost effective, reliable and flexible solution for the stabilization of frequency in a Wind Energy Conversion System.

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