Performance comparison of Wind Energy Conversion System fed to Back-to-Back Converter and Matrix Converter

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***Abstract*— Normally the output of the wind energy conversion system is directly connected to load or grid. For this purpose, we use power electronic converter circuits. In this paper, we use a matrix converter connected to the wind energy conversion system which helps in improving the terminal voltage and frequency control in induction generator, for all wind velocities. For enhancing the power captured from the wind, the shaft need to be controlled. Power electronic converters are used to interface the induction generator with the grid and maximize the power captured from the wind. The wind energy conversion system is compared using the topologies; back-to-back converter and matrix converter. The simulation results of wind energy conversion system are compared when connected with the back-to-back converter and matrix converter.**

***Index Terms*—Wind Energy Conversion System (WECS), Doubly fed Induction Generator (DFIG), Matrix Converter (MC)**

I. INTRODUCTION

Now-a-days due to the ever increasing population, the demand of electricity is also increasing simultaneously. In India the electrical power generation mainly depends on conventional energy sources such as coal, water, gas and nuclear elements such as uranium. But within short duration of time the coal and gas resources are going to be exhausted. The power generation using nuclear elements is an efficient one, but the main disadvantage is the cost of the uranium, which is highly economical and the other is the dumping of wastages coming from these plants involves high risk which causes radiation. The other conventional energy source is water, which is not constantly available throughout the year. Due to these facts we have to look after the other alternative energy resource for electrical power generation.

The alternative energy sources available are sun, wind, hydrogen gas and bio-mass. These are non-polluted resources and will not extinct. In India, the availability of solar radiation from sun, wind energy, hydrogen gas is high. But the conversion of energy from these sources into electricity is less for solar and hydrogen gas, when compared to wind energy. Keeping this advantage in view, in this paper, we concentrated on the electrical power generation using wind turbines.

Doubly fed Induction Generators are the most common type of advanced wind turbine generators due to their durability, low cost, simple in structure and ability to adjust reactive power. The major application of DFIGs is a variable speed generation, which in this case it is a popular generator for wind energy conversion system applications.

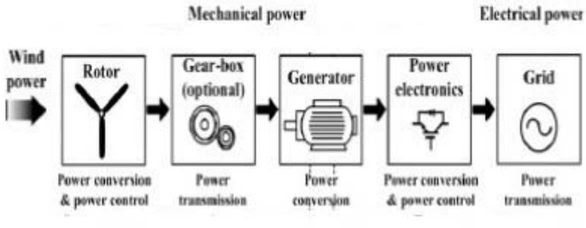

Fig1: General mechanism of Wind Energy Conversion System

II. Mathematical modeling of Wind Turbine

The law behind the working of wind turbine is *Betz's law* which states that, it is derived from the principle of conversation of mass and momentum of the air stream flowing through an actuator disk that extracts energy from wind stream. According to Betz law, the amount of kinetic energy that can be captured from any wind turbine is not more than 59.3%.

The Wind Turbine blade extracts the kinetic energy in the wind and transforms it into mechanical energy. The kinetic energy in the air of an object of mass 'm' moving with speed 'v' is equal to:

$$E = \frac{1}{2}m.v^2 \qquad (1)$$

The energy contained by the wind is in the form of kinetic energy, its magnitude depends on the air density and wind velocity.

The power extracted from the wind is given by:

$$P_m = \frac{1}{2}C_p(\lambda,\beta)\rho.A.v^3 \qquad (2)$$

Where C_p = Power Coefficient

A = Area swept by the turbine blade in (m^2) = $\pi.R^2$

V = Wind Velocity in (m/Sec)

If the rotor of the wind turbine turns too slowly, most of the wind will pass undisturbed through the gap between the rotor blades. Alternatively, if the rotor turns too fast, the blades will appear like a solid wall to the wind. Therefore, wind turbines are designed with optimal tip speed ratios to extract as much power as possible from the wind.

The torque of the Wind Turbine can be computed as:

$$T_w = \frac{P}{w_r} = \frac{\frac{1}{2}C_p(\lambda,\beta)\rho.A.v^3}{w_r} \quad (3)$$

$$T_w = \frac{\frac{1}{2}C_p(\lambda,\beta)\rho.\pi.R^2.v^3}{w_r} \quad (4)$$

Where, $w_r = \frac{2\pi N}{60}$

$$C_p(\lambda,\beta) = C_1(C_2\frac{1}{\gamma} - C_3.\beta - C_4.\beta^x - C_5)e^{-C_6/\gamma}$$

$$\frac{1}{\gamma} = \frac{1}{\gamma+0.08\beta} - \frac{0.035}{1+\beta^3}$$

The turbine itself is quite heavy and the machine rotor is light. The Shaft connecting the generator and the turbine cannot be assumed to be of infinite stiffness. The gearbox reduces the stiffness, therefore the shaft will twist as it transmits torque from one end to another.

A horizontal Wind Turbine is coupled with a gearbox to capture and transfer energy to the generator.

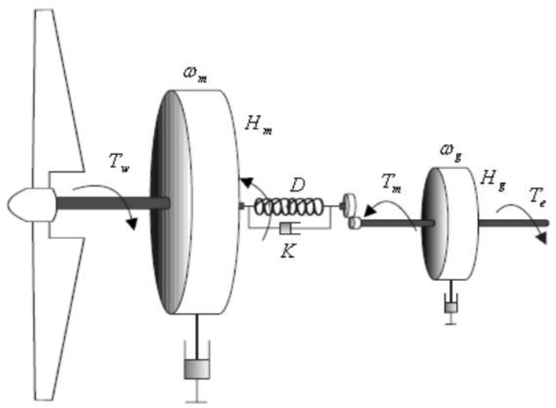

Fig2: Drive Train and Gear Box mechanism

The drive train of a Wind Turbine system is generally consists of a blade pitching mechanism, a hub with blades, a rotor shaft and a gearbox with a generator. The drive train model presented in this paper includes the inertia of both the turbine and the generator. The moment of inertia of the wind wheel is about 90% of the total drive train, while the generator rotor inertia is equal to about 10%.

The equation of motion of Induction Generator is given by:

$$H_g.\frac{dw_g}{dt} = T_e.\frac{T_m}{n} \quad (5)$$

The wind turbine shaft and generator are coupled together via a gearbox, the wind turbine shaft system should not be considered stiff. To account for the interaction between the windmill and the rotor, an additional equation describing the motion of the windmill shaft is to be adopted.

$$H_m.\frac{dw_m}{dt} = T_w - T_m \quad (6)$$

The mechanical torque T_m can be modeled by the equation:

$$T_m = K.\frac{\theta}{n} + D.\frac{w_g-w_m}{n} \quad (7)$$

A wind turbine will produce the most power when the turbine and generator are both operating at the optimal RPM. Gears are how they make that happen. Changing the gear ratio to make them spin at other RPM's will reduce efficiency. When small gear is attached with the generator, it rotates faster and produces higher voltage.

Where n = gear ratio; θ = angle between turbine rotor and generator rotor; w_m = Turbine rotor speed; w_g = Generator rotor speed; H_m = Turbine rotor inertia constant; H_g = Generator rotor inertia constant; K = drive train stiffness; D = drive train damping constant; T_w = Torque provided by wind; T_e = Electromagnetic torque

III. Power Converter Topologies

Basically two power converter topologies with full controllability of the generated voltage on the grid side and the controllability of magnetizing and torque currents on rotor side are currently used in the wind turbine systems. Power converter topologies can improve dynamic and steady state performances, helps to control the wind turbine generator.

A. Back – to – Back Converter:

To convert the mechanical energy generated by the wind turbine to electrical energy, we need a generator. As the wind turbine is variable speed of nature, we are choosing doubly fed induction generator for power conversion as its nature is fixed power conversion, even though its input is variable.

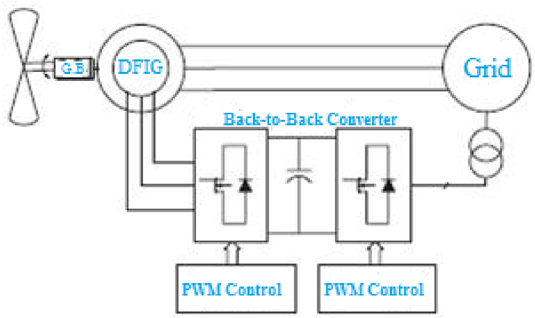

Fig3: WECS when connected to Back-to-Back Converter

The stator windings of DFIG are connected directly to the grid and rotor windings are connected to the grid by power electronic converters through slip rings. The energy delivered to the grid can be operated at both sub-synchronous and super synchronous speeds of DFIG.

In general the DFIG is connected to the back-to-back converter is used, which consists of two bi-directional pulse width modulation voltage source converters sharing a common DC link capacitor. One converter in the back-to-back converter is connected to the rotor of DFIG, while the other is connected to the grid.

The main reason in selecting the back-to-back converter here is, it has the ability to control active and reactive power, which is delivered to the grid, which gives the potential for optimizing the grid integration with respect to steady state operation conditions, voltage, angular stability and power quality.

The DC link voltage must be boosted to a higher level than the amplitude of the grid line-line voltage, to achieve the full control of the grid current. The change of magnitude of the real power can be observed with the change in the wind speed.

Irrespective of the wind, the DFIG produces a negative wind speed, which indicates that the flow of real power always flows from the machine to the grid.

The advantage of using capacitor decoupling between the grid side converter and the rotor side converter offers separate control of the two converters, allowing the asymmetry compensation independence on both sides of the converters. Switching losses are the major drawback of using a back-to-back converter. As there are two converters here, the switching losses are more. Extra EMI filters are required for high switching speed to the grid. By placing a filter the voltage gradient has to be limited, to avoid bearing current problems and to prevent high stresses on the generator insulation.

B. Matrix Converter

The main advantage of matrix device is elimination of the DC link filter. Zero shift loss devices will transfer input power to output power while not any power loss. However much it will not exist. The shift frequency of the device decides the doctorate of the device. Most power transfer to the load is determined by nature of the management algorithmic program. Matrix device encompasses a most input, output voltage transfer quantitative relation restricted to eighty seven anticipating curved input and output waveforms, which might be improved. Further, matrix converter needs additional semiconductor devices than a typical AC-AC indirect power frequency converter. Since monolithic bi-directional switches square measure obtainable they\'re used for shift purpose.

The AC/AC converter is usually classified as an indirect converter that utilizes a DC link between the two AC systems and converter that provides direct conversion. This converter consists of two converter stages and energy storage part, that converts input AC to DC and then reconverting DC back to output AC with variable amplitude and frequency. The operation of this device stage is decoupled on an immediate basis by the energy storage parts and controlled severally, farewell because the average energy flow is equal.

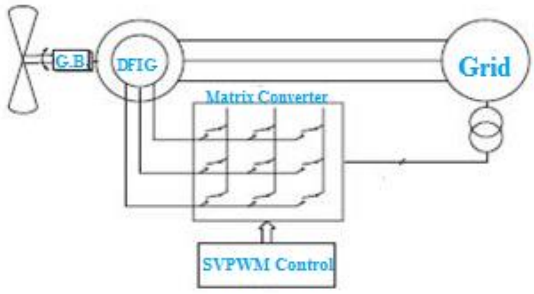

Fig4: WECS when connected to Matrix Converter

The instant power flow will not have to equal power output. The distinction between the input and output power should be absorbed or delivered by an energy storage part among the converted. The matrix converter replaces the multiple conversion stages and therefore the intermediate energy storage part by one power conversion stage, and uses a matrix of semiconductor bidirectional switches connecting input and output terminals. With this general arrangement of switches, the power flow through the converter will reverse.

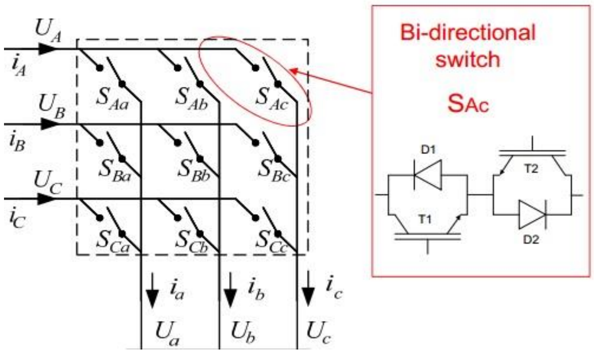

Fig5 : Matrix Converter Switching Pulses

As a result of the absence of any energy storage part, the instant power input should be equal to the power output, assumptive idealized zero-loss switches. However, the reactive power input will not have to equal power output. It will be aforementioned once more that the phase angle between the voltages and currents at the input is controlled and doesn't need to be an equivalent as at the output.

Three phase matrix converter consists of nine bidirectional switches. It's been organized into three groups of three switches. Every cluster is connected to every phase of the output.

Normally, the matrix converter is fed by a voltage supply and, for this reason; the input terminals shouldn't be short circuited. On the opposite hand, the load has generally an inductive nature and, for this reason, an output phase must not ever be opened.

Defining a single switch functioning as:

$$S_{kj} = \begin{cases} 1, switch\ S_{kj}\ closed \\ 0, switch\ S_{kj}\ opened \end{cases} \quad (8)$$

K = {A,B,C}   j = {a,b,c}

The constraints discussed above can be expressed by:

$$S_{Aj} + S_{bj} + S_{cj} = 1, j = \{a,b,c\} \quad (9)$$

The load and source voltages with reference to supply neutral are considered by:

$$V_o = \begin{bmatrix} V_a(t) \\ V_b(t) \\ V_c(t) \end{bmatrix} \quad V_i = \begin{bmatrix} V_A(t) \\ V_B(t) \\ V_C(t) \end{bmatrix} \quad (10)$$

The above Matrices can be re-written as:

$$\begin{bmatrix} V_a(t) \\ V_b(t) \\ V_c(t) \end{bmatrix} = \begin{bmatrix} S_{Aa}(t) & S_{Ba}(t) & S_{Ca}(t) \\ S_{Ab}(t) & S_{Bb}(t) & S_{Cb}(t) \\ S_{Ac}(t) & S_{Bc}(t) & S_{Cc}(t) \end{bmatrix} \begin{bmatrix} V_A(t) \\ V_B(t) \\ V_C(t) \end{bmatrix} \quad (11)$$

$$V_o = T.V_i \quad (12)$$

Where T is the instantaneous transfer matrix.

In order to derive modulation rules, it's additionally necessary to think about the switching pattern that's used.

IV. Simulation Study

The proposed topology using back to back and matrix converters delineated in the above is simulated using MATLAB for the DFIG operation in a WECS for totally different wind velocities for the system to operate in each sub-synchronously yet as super-synchronous speeds. The generator speed is adjusted such that maximum power are often controlled at a given wind velocity.

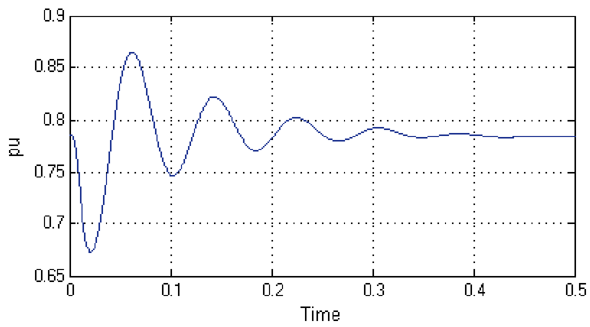

Fig6: Output waveform of Wind Torque

For a generator to convert mechanical energy to electrical energy, a torque is needed, for which we are using the torque that is generated by Wind Turbine. The output waveform of wind torque is shown below:

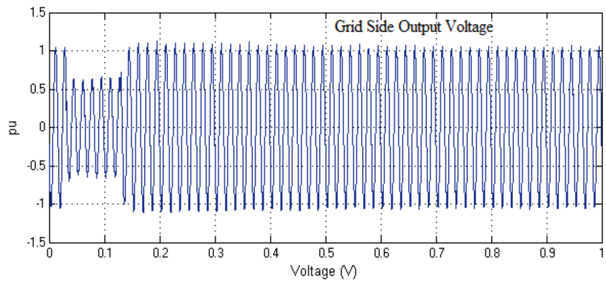

Fig7: Output Voltage waveform at Grid Side when connected to Back-to-Back Converter

Wind energy conversion system models are developed using back to back convertor and the matrix convertor with DFIG. DFIG is operating in a generating mode for a wide selection of wind speed and also the power is flowing from WECS to the grid in each topology.

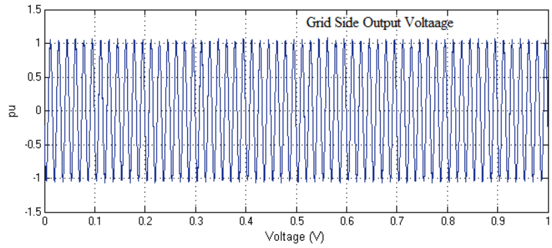

Fig8: Output Voltage waveform at Grid Side when connected to Matrix Converter

This shows that using MC with DFIG in WECS net performance of the system improves. It ensures the continual flow of power from the machine to the grid. Satisfactory current and voltage profile is achieved as compared with the back to back converter.

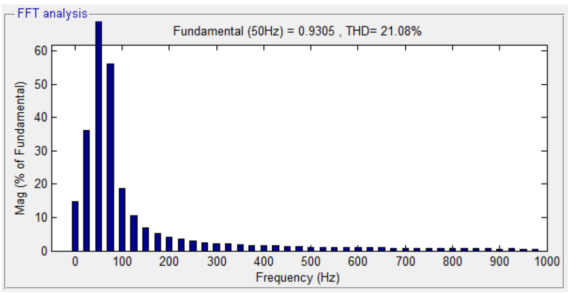

Fig9: FFT analysis of Grid Side Voltage when connected to Back-to-Back Converter

The results of simulation shows that the WECS has usually generated the power thus connected with the grid. Power is flowing from WECS to the connected grid. Thus, using the MC with DFIG in WECS improves net performance of the system.

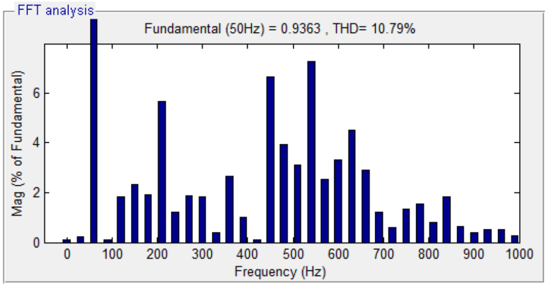

Fig10: FFT analysis of Grid Side Voltage when connected to Matrix Converter

Comparison of two Converter Topologies:

Parameters	Back – to – Back Converter	Matrix Converter
Converting Stages	Two	One
Maximum Frequency Limit	Low	High
Switching Stresses	High	Low
DC-Link	Required	Not required
Size of Filter	High	Low
DSP chips required to generate PWM Pulses	Two	One

V. Conclusion

WECS using DFIG models are developed and simulated using back to back converter and the matrix converter in MATLAB. DFIG for each topology using back to back converter and the matrix converter operated in generating mode for the wide selection of the wind speed.

It is concluded that the system takes 3 times less time to stabilize once the matrix converter is employed as compared to back to back converter. Torque quality and voltage stability is healthier in matrix converter as compared to back to back fed DFIG. Hence, matrix converter is additional appropriate for application within the wind energy conversion system that is obtaining advanced day by day exploitation advanced power electronics.

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