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Nine Switch Back To Back Converter- Design and Simulation for Wind Turbines Based on Doubly Fed Induction Generator

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***Abstract:** A conventional power system diverges from a Wind Energy Conversion System (WECS). The power output from a wind turbine system varies as the wind varies. Thus, management, design and analysis of WECS become difficult. Various approaches are available theoretically to cram the behavior of WECS. This paper, uses MATLAB simulink model of DFIG based WECS to study steady state characteristics. The analysis is performed to inspect the characteristics of wind and Doubly Fed Induction Generator model. For efficient generation of electricity, it is necessary to operate the wind turbine at variable speed. This is achieved by the Power Electronic Converters. Many designs of converters are available, depending on the aspects of economy, configuration and application. Now-a-days attention of the researchers is diverted towards the Doubly Fed Induction Generator (DFIG). The paper signifies the design, simulation and analysis of back-to-back converters for DFIG based Wind Energy Conversion System WECS. A 9- switch Back to Back converter is designed, simulated in the paper and the results are compared with traditional AC-DC-AC converter. The functioning of the converter is simulated by means of MATLAB/SIMULINK. Results of the simulation illustrate the improved DC link voltage, when compared to that of the conventional converter.*

I. INTRODUCTION

To answer the load, at present, renewable energy sources are more and more employed. Among these renewable, the wind power is on the rise rapidly around the world. This development is due to research efforts in this domain. Now a day's more notice is been given to this type of energy source, because of increasing requirement of high quality and consistent supply. The voltages and frequencies generated from these generators cannot be unswervingly connected to the grid. It becomes necessary to vary the voltage and frequency, before the interconnection of generator to the grid. Power electronics is increasingly being used by various systems related to industrial equipment and power generation [1]. In distributed generation (DG), Power quality is one of the major areas of concentration.

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During peak or low demand time, the voltage drop and voltage rise have to be evaded. The generators must be controlled for this to happen. Electricity generated through wind turbines is widely used in distributed generation systems [2, 3].

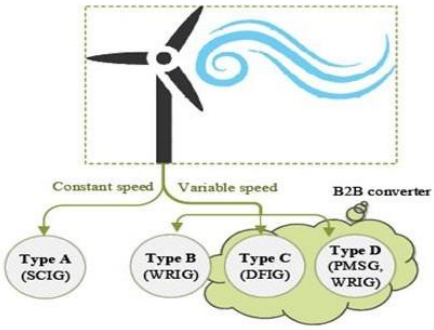

Fig.1 Wind Turbine Generators

Wind turbine generation is widely used sources. Wind turbine generators are categorized into two groups as shown in Fig 1. Depending on the operation, topology of interconnection to the grid, generator types and controlling methodologies, the variable speed generators are alienated in four types [7].

The first type is the asynchronous Squirrel Cage Induction Generator (SCIG). This type of generator uses a fixed-ratio gearbox to couple the rotor to the generator shaft, and operates on constant speed. Unfussiness is the major pro of these kinds of generators; yet, low efficiency and drawing pulsating reactive power are the foremost weakness. However in variable speed wind turbine category, type B, type C, and type D fall. The turbines of type B are interconnected to the network via a variable rotor resistance, to the network, and operate on fractional variable speed through a Wound Rotor Induction Generator (WRIG).

DFIG is controlled by a fractional scale power converter and directly interconnected to the network and forms Type C turbines.

As compared to type A and type B, even though DFIG has enhanced recital and efficiency, it still requires maintenance of the brushes of the rotor slip rings.

Type D generators include synchronous generators, generally Permanent Magnet Synchronous Generator (PMSG) furthermore known as Wound Rotor Synchronous Generator (WRSG), are in straight line connected via a full-scale converter to the grid. Such wind turbines does not require a gearbox, and run at low speed. These require less maintenance, mainly opted for offshore purpose [8].

The C and D types are preferred now-a-days, because of their high efficiency and low maintenance [2]. In DFIG, the generator's stator is connected to the grid directly while back-to-back converters are used to connect generator's rotor to the grid. Vector control is used to control DFIG and to decouple reactive and active power flow [5].

In DFIG, during some operation ranges when the rotor energy comes back to the converter, it is necessary to control of a Doubly-Fed Induction machine, and is achieved by a B2B converter. In a DFIG, the power flows in, to and fro direction via a B2B converter. Fig.2 shows the basic layout of the planned system.

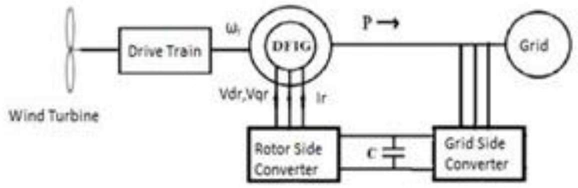

Fig.2 Block Diagram of the proposed system

II. DOUBLY FED INDUCTION GENERATOR

Because of the relative beneficial features like, the operational simplicity, maintenance, low cost, well active response, ability to generate power at varying speed, its rugged construction, brushless, and self protection against faults. The Induction generators are more and more used these days, over conventional synchronous generators. The later feature makes possible, the working or operation of the induction generator to provide supply to remote and far flung areas wherever grid expansion is not economically feasible, by operating the machine in stand- alone/ isolated mode. DFIG's undeniably are popular among copious variable speed concept because of several advantages. In these DFIG wind turbines, the converter can be designed for moderately low rating, just about 20% of the entire machine power [4]. The Doubly Fed Induction Generator (DFIG) is as shown in Fig. 3 Operation at variable rotor speed, control of the power, and production of electrical power at inferior wind speeds, are some of the advantages of a DFIG employed in wind turbines. The GSC- Grid Side Converter along with the RSC- Rotor Side Converter via a back to back converter are connected to control the wind power when the rotor of the DFIG is interconnected to the grid. By controlling net current, net active and reactive power production can be controlled via Grid Side Converter GSC.GSC pedals grid side region of the B2B converters. The RSC controls the stator active power, electrical torque, and stator reactive power creation, by controlling rotor current and RSC output voltage.

Rotor power (active) is equal to dc link capacitor power, net GSC active power, by holding DC link voltage stable (neglecting the losses taking place in power electronics). This configuration, wherein the B2B

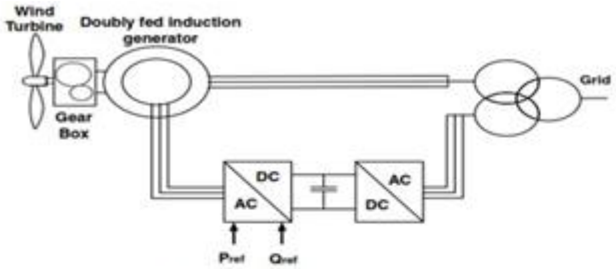

Fig.3 Doubly Fed Induction Generator Layout

PWM converter is connected to DFIG, the two way power flow is conveyed amid the grid side and the rotor side. With a constant dc-link voltage, input power from the grid side and input power to the generator rotor side must be equal.

Assume P_{mech} (neglecting losses in the generator), the turbine's mechanical transformed into P_g, being electric power, that is conveyed the power grid. The power in the rotor being slip power,

$P_r = -sP_g$ This can be equated as: $P_g = P_{mech} + sP_g$.

Difference between the speed of the rotating stator field and the rotor speed is defined as slip and is given as; $s = (n_s - n)/ns$. The slip is negative, the indication of power P_r then will be positive (flowing into the grid), in generating mode. Whereas in the motoring mode, the power P_r is negative (from the grid) and the slip s is positive.

III. BACK TO BACK CONVERTER

Two level B2B voltage source converters have two PWM power converters with a regular DC link. The topology is shown in Fig 4. These are the bi-directional power converters. In super-synchronous operation of DFIG, the RSC functions as an inverter and the GSC functions as a rectifier. During sub-synchronous mode, the rotor power transforms the direction. This permits the system to trail the optimum tip speed in a larger speed range. By means of this topology it is achievable to attain variation of speed of the induction machine from approximately 50% beneath synchronous speed to 50% beyond [9]. The back-to-back system is in addition capable to offer harmonic compensation and reactive power control both by the GSC and the RSC [1]. Employing DFIG with a power converter linked to the rotor permits recuperation of the slip power. The AC power impended from the rotor; however its frequency is that of the slip multiplied by the line frequency. Therefore, the grid cannot be supplied directly with the slip power. The slip power is first rectified to DC and then inverted to AC, to feed into the grid. [9].

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Both the converters of the B2B two level converter are operated independently and the merely dissimilarity flanked by the rectifier and inverter is the description of the power sign. Therefore the operating principle of B2B converters can be explained by inspection of only one of the converters[9].

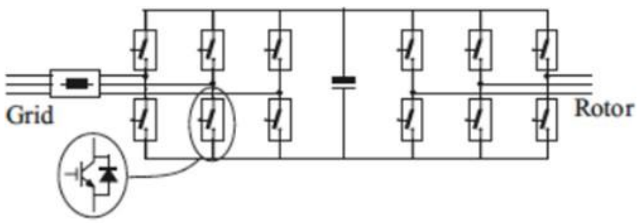

Fig.4 Two level Back to Back VSC topology

Rectifier operation:- An AC is converted to DC by rectifier. This straightforward rectification process generates a type of DC described by pulsating voltages and currents. Depending on the form of end-use, this type of DC current may be auxiliary customized into a comparatively constant voltage DC. Rectifier action in the back-to-back converter is six-pulse, three-phase, full-wave rectification. Six-pulse refers to the number of DC "pulses" for every 360° of electrical rotation, i.e for a complete period[11].

DC-link:- The path for the current to flow between a rectifier and an inverter is provided by a DC-link. DC-link is an energy storing element, the capacitor, required to smooth out the converter's DC ripple content and provides a firm input to the inverter. The load resistance and the capacitor have archetypal time constant $T = RC$ that is equal to the time taken for the capacitor to discharge to 37 % of its initial voltage. The grid to a large extent is decoupled from the generator, due to the capacitor. This is favorable for control purpose, in addition in case of faults as well [11].

Inverter operation :- By means of the inverter's active switching elements, the DC voltage is transformed to quasi-sinusoidal AC voltage output. Insulated-gate bipolar transistors (IGBT) are the most common members used as the inverter switching device. The output of the inverter attains eight diverse switch amalgamations. The voltage source inverter can synthesize the desired output voltage by controlling the switches, acknowledged as modulation [11].

IV. METHODOLOGY

The methodology includes, modeling of the DFIG based wind turbine model. At first while modeling the wind turbine model is derived in section 4.1, wherein the characteristics of wind is designed and analyzed for the optimum value of beta and tip speed ratio. In the next step, the wind turbine DFIG model is designed using mathematical modeling using abc transformation in section 4.4 by using electrical and mechanical relations in section 4.2 and 4.3 respectively. To this model, traditional AC-DC-AC converter is employed and simulated. Additionally a nine switch back to back converter is designed in section 4.5 using PWM technique, and the simulated THD results of the two converters are compared. All of the modeling, simulation, and analysis is carried out in MATLB SIMULINK.

4.1 Wind turbine modeling

Considering the wind speed, area of blades, air density and power coefficient, the power generated by wind turbine, can be calculated through the following equation:

$$P_w = \frac{1}{2}\rho A V^3 C_p(\beta,\lambda) \quad (1)$$

Where,

P_w = Power generated by the wind turbine

ρ = Wind density (which typically is 1.225 kg/m^3 at sea level for the normal temperature of 15°C and an atmospheric pressure of 101.325 kPa)

A= Area swept by the turbine

v^3= Wind Speed

C_p = Power Coeffecient

B = Pitch angle

λ= Tip Speed Ratio

$$\lambda = \frac{R\omega_m}{v} \quad (2)$$

In the above equation,

R=Radius of the blades ω_m=Rotational velocity

The Power coefficient signifies the fraction of the power in the wind confined by the turbine and has a theoretical maximum of 0.59, known as the Betz limit. The power coefficient can be expressed by a typical empirical formula as:

$$C_p = 0.576 * (\frac{116}{\lambda_i} - 0.4 * \beta - 5)e^{\frac{-21}{\lambda_i}} + (0.0068 * \lambda)$$

(3)

Therefore, the power coefficient can be changed and the power captured by the turbine can be controlled by varying the pitch angle. Fig 5 shows the MATLAB simulink wind turbine model, which is simulated for tip speed range of 0-15,
pitch angle 0-20°.

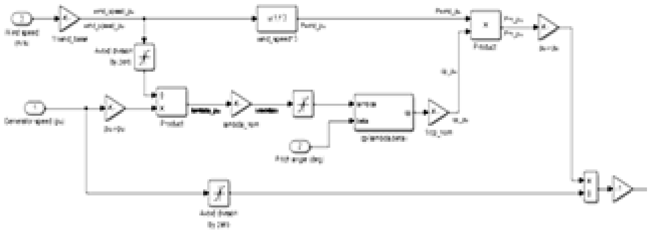

Fig.5 Wind Turbine model

Some of the advantages is the

converter capacity, being only 1/3 of the generator's power, lesser expenditure on the system, whilst improving the power quality [12].

4.2 Electrical relations

Using the Kirchhoff's and Faraday's law, the voltage relations on rotor and stator sides are deduced as:

$$\begin{bmatrix} v_{as} \\ v_{bs} \\ v_{cs} \end{bmatrix} = R_s \begin{bmatrix} i_{as} \\ i_{bs} \\ i_{cs} \end{bmatrix} + \frac{d}{dt} \begin{bmatrix} \varphi_{as} \\ \varphi_{bs} \\ \varphi_{cs} \end{bmatrix} \quad (4)$$

$$\begin{bmatrix} v_{ar} \\ v_{br} \\ v_{cr} \end{bmatrix} = R_r \begin{bmatrix} i_{ar} \\ i_{br} \\ i_{cr} \end{bmatrix} + \frac{d}{dt} \begin{bmatrix} \varphi_{ar} \\ \varphi_{br} \\ \varphi_{cr} \end{bmatrix} \quad (5)$$

The stator and rotor quantities are represented by subscripts s and r, respectively. For phase quantities of a, b and c, the subscripts a, b and c are used. The stator and rotor winding resistances are R_s and R_r.

4.3 Mechanical relations

Uptil now, using the stator reference frame, the electrical properties of the DFIG are developed.

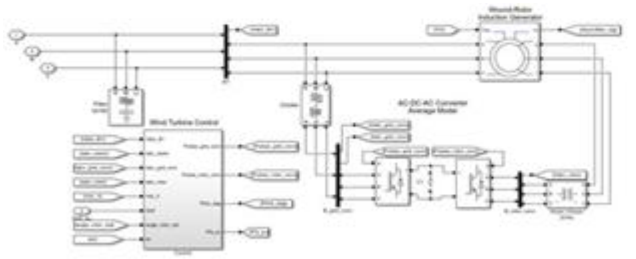

Fig.6 DFIG MATLAB simulink model

Model of the mechanical dynamics is to be derived, In order to absolute the model. The rotor speed and the electromagnetic torque are related by the dynamics of the generator shaft:

$$J\frac{d\omega_m}{dt} = T_m - T_e \quad (6)$$

J being the machine inertia, T_e is the electromagnetic torque, T_m is the mechanical torque.

*4.4 dq*0- reference frame

An appropriate reference frame model can be chosen to achieve a simpler model. Preferring the *dq*0-reference frame, wherein the stationary stator reference frame is related to its displacement and also is the rotating reference frame.

Let ***T****dq*0 (*ß*) be the rotation matrix which the *dq*0- reference frame is obtained by transforming the *abc*-quantities:

$$Tdq0(\beta) =$$

$$\frac{\sqrt{3}}{2}\begin{bmatrix} \cos(\beta) & \cos\left(\beta - \frac{2\pi}{3}\right) & \cos\left(\beta + \frac{2\pi}{3}\right) \\ -sin\beta & -sin\left(\beta - \frac{2\pi}{3}\right) & -sin\left(\beta + \frac{2\pi}{3}\right) \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \quad (7)$$

Hence, abc and dq0 quantities can be related as:

$$\vec{f}_{dq0} = T_{dq0}(\beta)\vec{f}_{abc} \quad (8)$$

With,

$$\vec{f}_{dq0} = \begin{bmatrix} f_d \\ f_q \\ f_0 \end{bmatrix} \quad (9)$$

$$\vec{f}_{abc} = \begin{bmatrix} f_a \\ f_b \\ f_c \end{bmatrix} \quad (10)$$

4.5 Converter

Modeling of RSC and GSC

There are two PWM inverters connected B2B via a DC link.

An AC voltage at power frequency is introduced by the GSC to the grid whereas, an AC voltage at is introduced by the RSC to the rotor slip frequency. It preserves the dc link voltage constant. The RSC and GSC are not the topic of focus. The power balance equation can be written as follows:

$$= P_{GSC} + P_{DC} \quad (11)$$

$$= V_{dr} i_{dr} + V_{qr} i_{qr} \quad (12)$$

$$= V_{dg} i + V_{qg} i_{qg} \quad (13)$$

$$P_{DC} = CV_{DC}\frac{dV_{DC}}{dt} \quad (14)$$

Where P_{RSC} is the power at RSC, P_{GSC} is the power at GSC, and P_{DC} is power at DC link. V_{dg}, V_{qg} , I_{dg}, I_{qg} are GSC side, AC voltages and currents at in dq frame, C- DC link capacitor value, V_{dc} – DC link voltage. Fig 7 shows a Back to Back converter with nine switches.

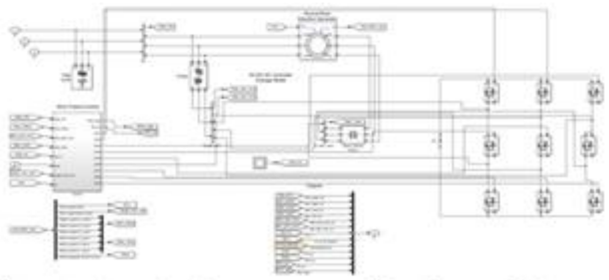

Fig.7 Back to back converter with nine switches

V. SIMULATION RESULTS

Here, the performance of B2B controller in the DFIG based wind turbine system is simulated in MATLAB. The wind turbine is modeled to validate the Betz limit, and the performance curves are as obtained below in Fig.8

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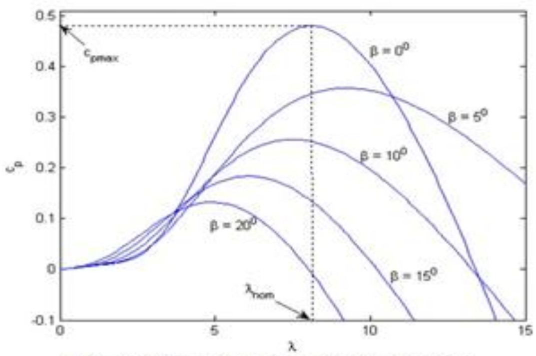

Fig. 8 Wind turbine characterstics

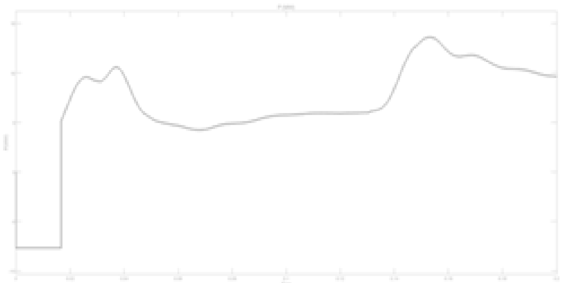

Fig 9 Real Power Curve for conventional AC-DC-AC converter

Further, the DFIG model is rigged up in the simulink with a traditional AC-DC-AC converter, and the following characteristics are obtained, as shown in fig 9-fig11.

Reducing the number of switches hands over many benefits over the traditional B2B converter

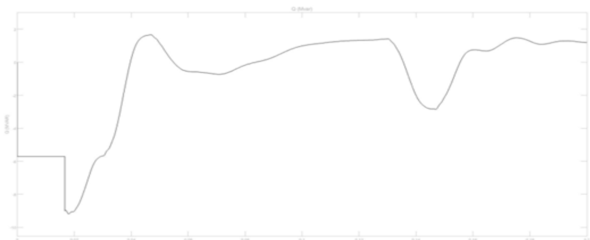

Fig 10 Reactive Power Curve for conventional AC-DC-AC converter

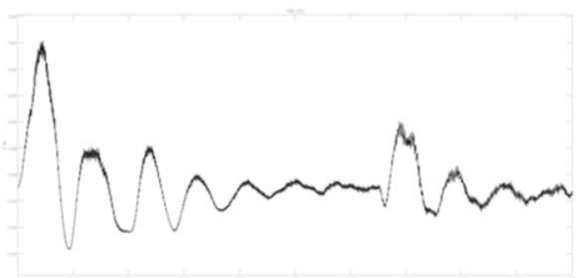

Fig 11 Voltage across DC-Link capacitor for conventional AC-DC-AC converter

Fig 12 Real Power Curve for 9-switch Back-to-Back converter

configuration, providing a higher power converter. Fig 12-fig14 describes the characteristics of a nine- switch back to back converter. In order to stabilize the DC link voltage and to control the reactive power, the Grid Side and Rotor side converter should inject maximum available active power to the grid. In this study, a nine switch Back to Back converter is employed.

Fig 13 Reactive Power Curve for 9-switch Back-to-Back converter

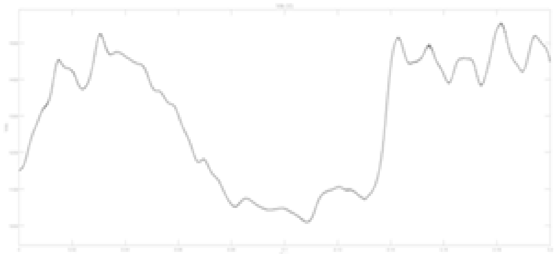

Fig 14 Voltage across DC-link Capacitor for 9-switch Back-to-Back converter

VI. CONCLUSION

Here, the model of DFIG based wind turbine, with 9 switch back to back converters is developed, simulated and analyzed. Assessing the system performance the nine switch B2B converter indicates the satisfying performance, in terms of real, reactive powers and stabilized DC link voltage. IEC 61000-3-2 confines the harmonics of different power equipment. Low THD is one of the important attribute specified by IEC. Higher the harmonic distortion, lower would be the efficiency, higher peak currents and lower power factor.Hence, in this paper a nine switch B2B converter is designed over a traditional AC-DC-AC converter.

Comparing the Harmonic distortions of the two converters reveal that the nine-switch B2B converter is far more efficient as its THD is less, which in turn reduces the peak currents and core loss in machines. *The THD obtained for a regular AC-DC-AC converter is 0.4018 %, however with nine-switch B2B converter the improved THD is 0.2542 %.*

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