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Modeling and Simulation of AC/DC In Wind Generation Fed Induction Motor Drive

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Abstract:
Wind power generation has been renowned as the most rapidly growing technology due to the increasing incursion of renewable energy resources in modern power system networks. In wind power generation, the use of two back-to-back ac/dc voltage source converters with a dc-link is very common in today's executions. The grid through a back to-back dc-link is connected to the rotor in DFIG wind applications. In this topology, the rotor-side converter is responsible for the control of the active and reactive power commuted between the stator and the grid, whereas the grid side converter (GSC) is responsible for the dc voltage regulation at a certain desired level and for the reactive power regulation at unity power factor operation. The control characteristics of the ac/dc grid-side voltage source converter (VSC) used to connect wind power systems with the grid are of significant grandness for the overall grid execution. The evolution of technology related to wind systems industry leaded 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 stator of the generator is directly connected to the grid while the rotor is connected through a back-to-back converter which is dimensioned to stand only a fraction of the generator rated power. In this project, voltage oriented control PI and phase locked loop (PLL) are used to regulate grid-side dc voltage and system power factor by decoupled control theory. Which verifies that the developed control mechanism is feasible to apply for grid-side converter based wind power generation system and the grid-side converter is controlled well by using MAT Lab/Simulink.

Keywords: ***Induction motor drive, voltage source inverter, wind energy conversion system, grid***

I.INTRODUCTION

In recent years, there has been an increasing awareness about the global warming and the harmful effects that the emissions of carbon have. This created a higher demand for clean and sustainable energy sources like: wind, sea, sun, biomass etc. The wind energy has experienced the biggest growth in the past 10 years. This is because wind energy is a pollution-free resource, has an inexhaustible potential and also because of its increasingly competitive cost. The size of the wind turbine installations has also grown from 300 KW in the early 1990, up to 10 MW capacity range presently. The main drawback of the wind is that it is irregular in occurrence. The problem becomes how to maximize the energy capture from the wind. 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. Based on the types of components used, different WECS structures can be realized. However, the objective in all structures is the same, i.e., the wind energy at varying wind velocities has to be converted to electric the grid frequency.

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The constant speed wind turbines and induction generators were often used, in the early stages of wind power development. Some of the disadvantages of the fixed speed generators are the low efficiency, poor power quality, high mechanical stress but also that by having a fixed speed operation the maximum coefficient of performance is obtained only at a particular wind speed. Due to development of power electronics and their falling costs, the variable speed operation became the most attractive option. Among all kinds of wind energy conversion systems (WECSs), a variable speed wind turbine (WT) equipped with a multi pole permanent magnet synchronous generator (PMSG) is found to be very attractive and suitable for application in large wind farms. With gearless construction, such PMSG concept requires low maintenance, reduced losses and costs, high efficiency and good controllability.

In wind power generation, the use of two back-to-back ac/dc voltage source converters with a dc-link is very common in today's executions [1]. For example, the grid through a back to-back dc-link is connected to the rotor in DFIG wind applications. In this topology, the rotor-side converter is responsible for the control of the active and reactive power commuted between the stator and the grid, whereas the grid side converter (GSC) is responsible for the dc voltage regulation at a certain desired level and for the reactive power regulation at unity power factor operation [2-5]. Also, in the cases of squirrel cage induction generators or permanent magnet synchronous generators wherein a similar dc-link is used, the main tasks of the GSC devices remain the same, i.e. dc-voltage and power factor regulation. It is well known that the wind power generation system with back to back voltage source converter control mechanism is very complex. Therefore the grid side voltage source converter based wind power generation system is only studied in this paper.

II.THREE PHASE GRID MODEL

Suppose the grid is a symmetrical three-phase voltage source. So its voltage model can be defined as follows:

$$\begin{cases} V_a = V_m.\cos(wt) \\ V_b = V_m.\cos\left(wt - \frac{2\pi}{3}\right) \\ V_c = V_m.\cos\left(wt - \frac{4\pi}{3}\right) \end{cases} \quad (1)$$

Similarly, its current model is defined as follows:

$$\begin{cases} i_{ag} = I_m.\cos(wt) \\ i_{bg} = I_m.\cos\left(wt - \frac{2\pi}{3}\right) \\ i_{cg} = I_m.\cos\left(wt - \frac{4\pi}{3}\right) \end{cases} \quad (2)$$

A.MODELING of THREE PHASE VSC EXPRESSED in ABC REFERENCE FRAME

The system under consideration, shown in Fig.1, represents a VSC connected to the grid through an R-L filter while the dc–side consists of a capacitor parallel with a resistance. The modeling and circuit analysis of VSC is given next. First, let us define S_k (k = a,b,c) as the switch function of phase, k.

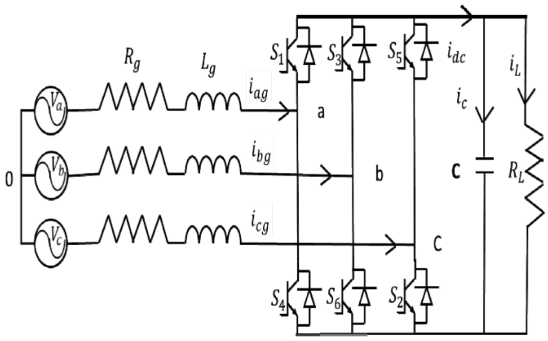

Fig.1 grid side VSC

Based on the principle that any two switches in the same leg cannot be on at the same time, one can write the following definition [6]:

$$S_k = \begin{Bmatrix} 1 & upper & IGBT & on \\ 0 & upper & IGBT & off \end{Bmatrix} \quad (3)$$

Applying Kirchhoff's laws to the circuit of Fig.1, the instantaneous values of the currents can be obtained, and written as following:

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$$\begin{cases} L_g \dfrac{di_{ag}}{dt} = V_a - R_g i_{ag} - V_{(a,0)} \\ L_g \dfrac{di_{bg}}{dt} = V_b - R_g i_{bg} - V_{(b,0)} \\ L_g \dfrac{di_{cg}}{dt} = V_c - R_g i_{cg} - V_{(c,0)} \end{cases} \quad (4)$$

Here, $V_{(a,0)}$, $V_{(b,0)}$ and $V_{(c,0)}$, are the voltages from the ac side of the VSC to the power neutral point 0, and can be obtained by (5).

$$\begin{cases} V_{(a,0)} = V_{(a,N)} + V_{(N,0)} \\ V_{(b,0)} = V_{(b,N)} + V_{(N,0)} \\ V_{(c,0)} = V_{(c,N)} + V_{(N,0)} \end{cases} \quad (5)$$

For a balanced three-phase system

$$V_{(a,0)} + V_{(b,0)} + V_{(c,0)} = 0 \quad (6)$$

Substituting from (5) into (6), the following (7) can be deduced as:

$$V_{(N,0)} = -\frac{V_{(a,N)} + V_{(b,N)} + V_{(c,N)}}{3} \quad (7)$$

Considering phase-a, when the upper IGBT is on and lower IGBT is off, $S_a = 1$ and $V_{(a,N)} = V_{dc}$. Similarity, when the upper IGBT is off and lower IGBT is on, $S_a = 0$ and $V_{(a,N)} = 0$. Therefore, based on the above characteristic, $V_{(a,N)} = V_{dc}.\ S_a$.

$$\text{Therefore} \begin{cases} V_{(a,N)} = S_a V_{dc} \\ V_{(b,N)} = S_b V_{dc} \\ V_{(c,N)} = S_c V_{dc} \\ V_{(N,0)} = -\dfrac{1}{3}(S_a + S_b + S_c) V_{dc} \end{cases} \quad (8)$$

Substituting from (5) and (8) into (4), the set of (9) derived as:

$$\begin{cases} L_g \dfrac{di_{ag}}{dt} = V_a - R_g i_{ag} - V_{dc}\left(S_a - \dfrac{1}{3}\sum_{k=a,b,c} S_k\right) \\ L_g \dfrac{di_{bg}}{dt} = V_b - R_g i_{bg} - V_{dc}\left(S_b - \dfrac{1}{3}\sum_{k=a,b,c} S_k\right) \\ L_g \dfrac{di_{cg}}{dt} = V_c - R_g i_{cg} - V_{dc}\left(S_c - \dfrac{1}{3}\sum_{k=a,b,c} S_k\right) \end{cases} \quad (9)$$

Under the assumption that the power switch resistances of a balanced three-phase system could be neglected, the power relationship between the ac side and dc side is given as follows:

$$\sum_{k=a,b,c} i_{kg}(t) V_{kN}(t) = i_{dc}(t) V_{dc} \quad (10)$$

By combining (8) with (10), the following (11) as:

$$i_{dc}(t) = i_{ag}(t) S_a + i_{bg}(t) S_b + i_{cg}(t) S_c \quad (11)$$

By applying Kirchhoff's laws to the positive node of the dc link capacitor, as follows:

$$\begin{cases} i_c = C \dfrac{dV_{dc}}{dt} \\ i_{dc} = i_c + i_L \\ i_{dc} = S_a i_{ag} + S_b i_{bg} + S_c i_{cg} \\ i_L = \dfrac{V_{dc}}{R_L} \end{cases} \quad (12)$$

(12) can also be expressed by a single equation, and given as follows [7]:

$$C \frac{dV_{dc}}{dt} = S_a i_{ag} + S_b i_{bg} + S_c i_{cg} - \frac{V_{dc}}{R_L} \quad (13)$$

For a balanced three-phase system

$$V_a + V_b + V_c = 0 \quad (14)$$

$$i_{ag} + i_{bg} + i_{cg} = 0 \quad (15)$$

Therefore, (9) along with (13) through (15) constitute the three-phase voltage source converter model expressed in the abc reference frame, and are rewritten as follows [8]:

$$\begin{cases} C \dfrac{dV_{dc}}{dt} = \sum_{k=a,b,c} S_k i_{kg} - i_L \\ L_g \dfrac{di_{kg}}{dt} + R_g i_{kg} = V_k - V_{dc}\left(S_k - \dfrac{1}{3}\sum_{j=a,b,c} S_j\right), k = a,b,c \\ \sum_{k=a,b,c} V_k = \sum_{k=a,b,c} i_{kg} = 0 \end{cases} \quad (16)$$

III.GRID SYNCHRONIZATION METHOD

The output voltage phase angle of the three phase system has to follow their respective grid voltage phase angle and, as a consequence, the reference currents will be in phase to their corresponding voltages. The independent synchronization can be implemented with a PLL shown in Fig.2

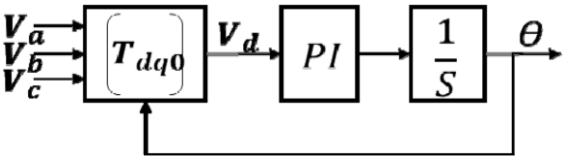

Fig.2 The configuration of three phase PLL

Where $$[T_{dq0}] = \frac{2}{3}\begin{bmatrix} \cos\theta & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta - \frac{4\pi}{3}\right) \\ -\sin\theta & -\sin\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta - \frac{4\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \quad (17)$$

B. MODELING of THREE PHASE VSC EXPRESSED in DQ SYNCHRONOUS REFERENCE FRAME

Although the voltage source converter model expressed in the abc frame has straightforward meanings, all the components in the abc model are time variant, which will bring troubles and difficulties to controller designs. Hence, it is necessary to transform the abc model to a dq model which rotates at synchronous speed, so that the three-phase voltage inputs and the current components will be transformed to dc values.

Applying the transformation matrix (17) in (16) and eliminating the zero-sequence components due to a balanced three-phase system, the VSC model expressed in the dq synchronous reference frame can be deduced and given as in [9], [10]:

$$\begin{cases} C\frac{dV_{dc}}{dt} = \frac{3}{2}\left(i_{dg}S_d + i_{qg}S_q\right) - i_L \\ L_g\frac{di_{dg}}{dt} - wL_g i_{qg} + R_g i_{dg} = V_d - V_{d1} \\ L_g\frac{di_{qg}}{dt} + wL_g i_{dg} + R_g i_{qg} = V_q - V_{q1} \end{cases} \quad (18)$$

Where, $V_{d1} = V_{dc}.\ S_d$ and $V_{q1} = V_{dc}.\ S_q$.

The active and reactive powers of a grid-side converter expressed in the dq synchronous reference frame are given as follows:

$$P_g = \frac{3}{2}\left(V_d i_{dg} + V_q i_{qg}\right) \quad (19)$$

$$Q_g = \frac{3}{2}\left(V_q i_{dg} - V_d i_{qg}\right) \quad (20)$$

PI CONTROL DESIGN of GRID SIDE VSC

Aligning the reference frame along the d-axis in the synchronous reference frame, the q-axis of the grid voltage, V_q, will be zero, while the d-axis of the grid voltage, V_d, will be a constant. From the above analysis and from (19) and (20), the active and reactive power of a grid-side converter under such reference frame will be proportional to the currents, i_{dg} and i_{qg} , respectively. The relationships are given as in [7]:

$$P_g = \frac{3}{2}V_d i_{dg} \quad (21)$$

$$Q_g = -\frac{3}{2}V_d i_{qg} \quad (22)$$

Since the objective is to yield a unity power factor looking from the grid-side, the reactive power should be zero, and thus the reference value for the q-axis current is zero. Hence, through controlling the d-axis and q-axis currents, the active and reactive power flow between the grid and the grid-side converter can be regulated. From (18), it can be seen that d- and q- axes equations have coupling components, $wL_g i_{qg}$ and $wL_g i_{dg}$. Therefore, a decoupled control scheme is recommended, and the corresponding control signals are given as follows [9], [5].

$$\begin{cases} V_{d1} = -R_g i_{dg} + wL_g i_{qg} + V_d + \Delta V_d \\ V_{q1} = -R_g i_{qg} - wL_g i_{dg} + V_q + \Delta V_q \end{cases} \quad (23)$$

The decoupled state equation is written as follows:

$$\begin{cases} L_g\frac{di_{dg}}{dt} + \Delta V_d = 0 \\ L_g\frac{di_{qg}}{dt} + \Delta V_q = 0 \end{cases} \quad (24)$$

In the grid side control, mainly dc-link voltage is compared with a reference dc-link voltage and error is fed to a PI controller to maintain constant dc-link voltage. In corresponds to the PI controller, a reference current is generated and q axis current component is

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set as zero, to maintain the flow of reactive power zero from the grid.

$$i_{gd}^* = \left(k_{p1} + \frac{k_{i1}}{s}\right)\left(V_{dc}^* - V_{dc}\right) \qquad (25)$$

Now, the reference grid converter currents and are compared with the actual grid currents in order to generate the control signals for grid converter as,

$$\Delta V_d = \left(k_{p2} + \frac{k_{i2}}{s}\right)\left(i_{gd}^* - i_{gd}\right) \qquad (26)$$

$$\Delta V_q = \left(k_{p3} + \frac{k_{i3}}{s}\right)\left(i_{gq}^* - i_{gq}\right) \qquad (27)$$

Choosing the dc-link reference voltage from (28).

$$V_{dc} \propto \frac{\sqrt{2}V_a}{m} \qquad (28)$$

The modulation signal for phase- a can be derived as follows [11]:

$$V_{ma} = \frac{2V_{a1}V_T}{V_{dc}} \qquad (29)$$

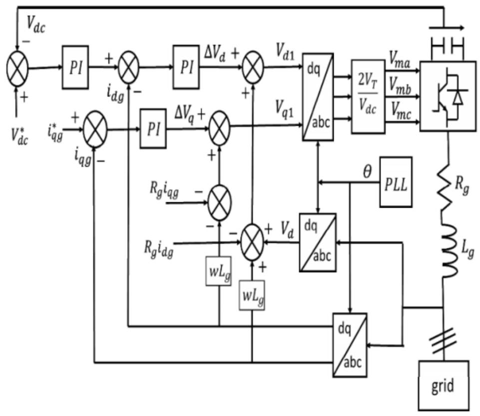

Fig.3 the control mechanism of grid side converter

IV.INDUCTION MOTOR

Induction Motor (1M) An induction motor is an example of asynchronous AC machine, which consists of a stator and a rotor. This motor is widely used because of its strong features and reasonable cost. A sinusoidal voltage is applied to the stator, in the induction motor, which results in an induced electromagnetic field. A current in the rotor is induced due to this field, which creates another field that tries to align with the stator field, causing the rotor to spin. A slip is created between these fields, when a load is applied to the motor.

Compared to the synchronous speed, the rotor speed decreases, at higher slip values. The frequency of the stator voltage controls the synchronous speed [12]. The frequency of the voltage is applied to the stator through power electronic devices, which allows the control of the speed of the motor. The research is using techniques, which implement a constant voltage to frequency ratio. Finally, the torque begins to fall when the motor reaches the synchronous speed. Thus, induction motor synchronous speed is defined by following equation, = Where f is the frequency of AC supply, n, is the speed of rotor; p is the number of poles per phase of the motor. By varying the frequency of control circuit through AC supply, the rotor speed will change.

V. MATLAB/SIMULINK RESUTS

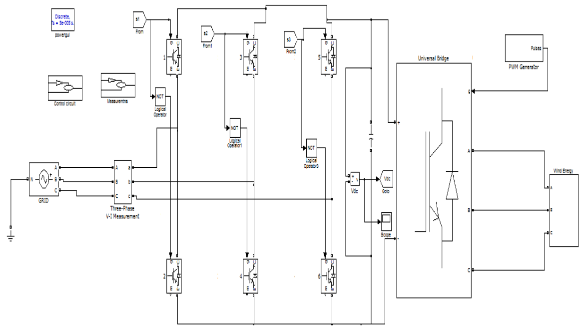

Fig.4.Simulink circuit for proposed system

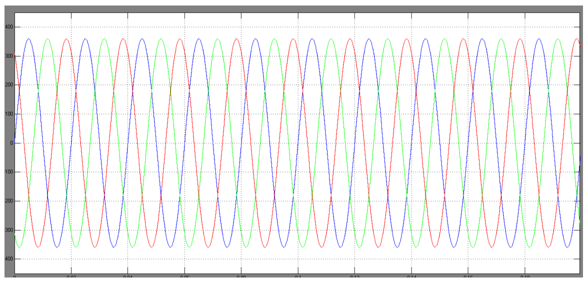

Fig.5.Simulation result for grid voltage

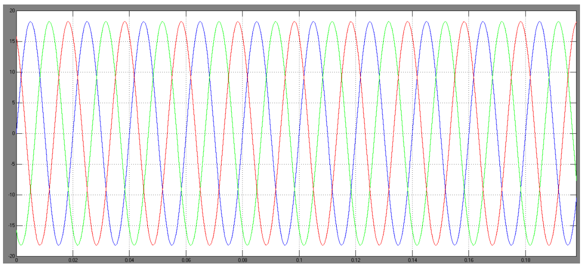
Fig.6.Simulation result for grid current

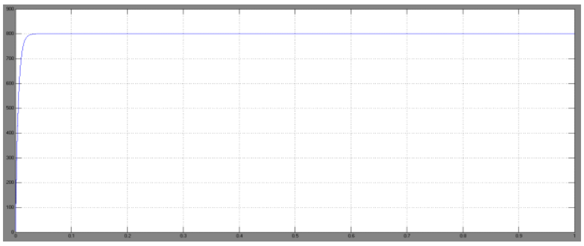
Fig.7.Simulation result for dc link voltage

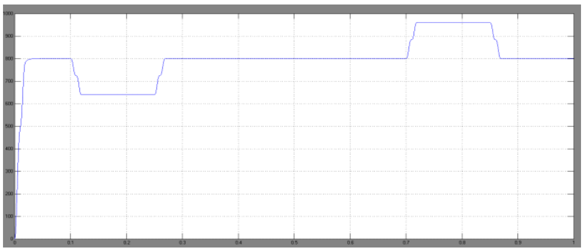
Fig.8.Simulation result for dc link voltage with grid sag and swell

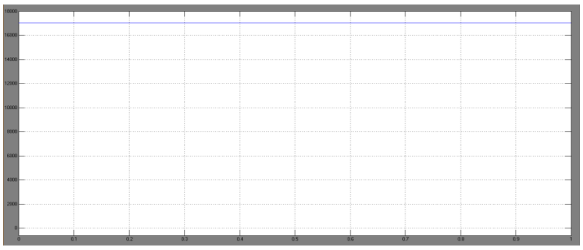
Fig.9.Simulation result for active power

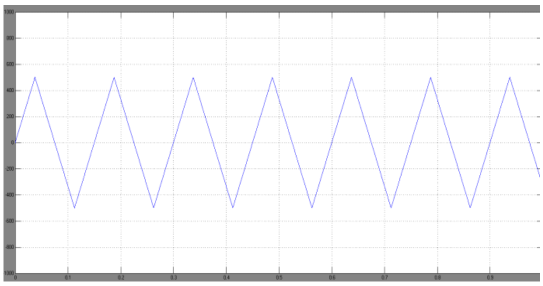
Fig.10Simulation result for reactive power

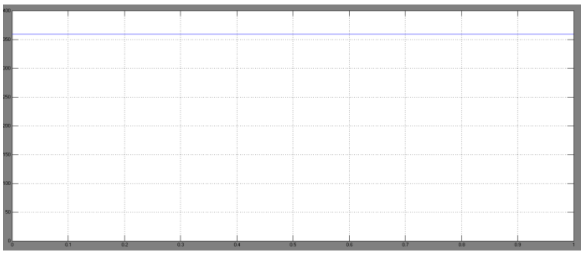
Fig.11.Simulation result for direct axis component

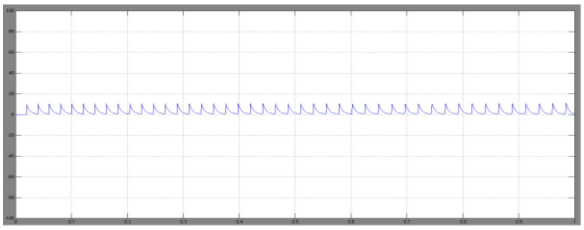
Fig.12.Simulation result for quadrature axis component

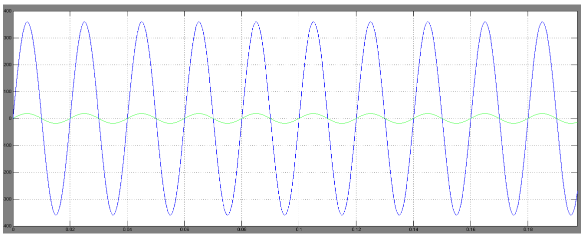
Fig.13.Simulation result for grid power factor

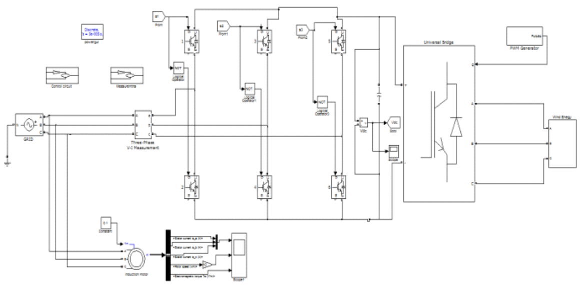
Fig.14.Simulink circuit for proposed system with induction motor drive

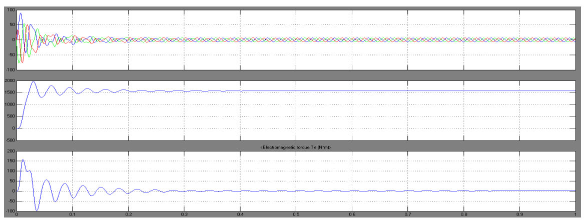
Fig.15.Simulation result for stator current, speed and electromagnetic torque of induction motor

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CONCLUSION

The detailed modeling and control of grid side VSC has been carried out for a wind power generation system. A configuration of a grid side VSC in the dc link has been proposed with a control strategy to maintain the grid power constant. In wind power generation application, the power flow in a back-to-back VSC is bidirectional. For synchronization, the machine side converter must be supplied with required power from dc link capacitor bank. Therefore the primary role of grid side VSC is to keep the dc link voltage constant. The performance of induction motor has been checked for this system by using MATLAB/Simulink.

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