Abstract—in recent years, wind energy has become one of the most important and promising sources of renewable energy, which demands additional transmission capacity and better means of maintaining system reliability. The 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 DFIG using MATLAB Simulation. DFIG is the hybrid version of the Induction Generator. In the DFIG no extra auxiliary equipment is required to compensate the reactive power because the design of DFIG is such a way that reactive power is compensated by the Rotor Side or Grid Side Converter. The rotor side converter (RSC) usually provides active and reactive power control of the machine while the grid-side converter (GSC) keeps the voltage of the DC-link constant. Results show that the DFIG can work at variable speed; it gives the optimum output at respective speed. But induction generator only works at fixed speed. The power output is more reliable in DFIG. In induction generator capacitor bank or STATECOM is used for compensating the reactive power. In DFIG there is no need of such equipment for compensating the reactive power, DFIG is more stable at Transient Fault Condition than IG.

Key words: DFIG; power flow of DFIG; MATLAB Simulation

I. INTRODUCTION

The totally installed wind power capacity is constantly increasing. Not only the overall installed wind power capacity, but also the average rated power per wind mill is constantly increasing [1]. Especially for wind mills above 2 MW, the doubly-fed induction generator is the most widely used generator concept (e.g. GE Wind Energy, Vestas, RE Power, Nordex, NEG Micon), but standard doubly fed induction machine models for modeling large power systems are still under investigation [2]. Among variable speed constant frequency wind turbines, a doubly fed induction generator (DFIG) has been known as a significant source for generation of electricity from wind due to its advantages [3]. The control and operation of DFIG systems have been primarily focused on grid-connected applications in the last decade considering modeling and control [4], direct power control [5], ride-through capability [6], unbalanced grid network [7–8], and distorted grid voltage [9–10]. In particular, when unbalanced voltage or harmonic distortions occur, high current together with torque and power oscillations caused by negative sequence or harmonic components during continuous operation could damage the generator. Therefore, several studies [11–12] proposed control techniques taking into account compensating unbalanced and distorted disturbances to deal with this problem. However, there are less technical articles considering standalone operation of a WECS, while a number of isolated customer loads have been significant.

There are many kinds of isolated loads such as remote villages, electric ships, military equipment’s, etc., which necessarily require a stand-alone generating system to supply power demand. The majority of stand-alone wind energy systems developed in the literature employs a squirrel-cage asynchronous induction generator with fixed-speed operation [13]. Meanwhile, there are not many publications associated with stand-alone DFIG applications but a little literature presented in [14–15]. The most important characteristic of a stand-alone DFIG is that the system itself has to generate a constant voltage and frequency in the stator side irrespective of varying rotor speed due to wind speeds and varying consumer loads. Therefore, voltage and frequency control in the stator of a stand-alone DFIG is extremely mandatory to ensure overall satisfactory performance. In reality, consumer loads contain both unbalanced loads and nonlinear loads such as diode or thyristor rectifiers, which cause unbalanced or distorted current and voltage waveforms in the stator and at the point of common coupling (PCC) of a DFIG. Therefore, if these influences are not taken into account and fully compensated, the operational efficiency of DFIG generation systems is strongly affected, degrading the performance of other loads connecting to the PCC. Several control strategies developed are aimed to eliminate these negative impacts.

II. DOUBLY FED INDUCTION GENERATOR

Figure 1 Shows a WECS using DFIG. A wind turbine catches the wind through its rotor blades and transfers it to the rotor hub. The rotor hub is attached to a low speed shaft through a gear box. The high speed shaft drives an electric generator which converts the mechanical energy to electric energy and delivers it to the grid [10–12]. As the wind speed varies, the power captured, converted and is given by

$$P = C_p \times \left(\frac{1}{2}\right) \rho \times A \times V^3$$

(2.1)

Where, $\rho$ is the air density in Kg/m$^3$, $A$ is the area covered by the rotor blades, $C_p$ is the performance coefficient of the turbine, $V$ is the wind speed. The performance coefficient $C_p$ is a function of the tip speed ratio, and the pitch angle of the rotor blades. It is determined by aerodynamic laws and thus may change from one turbine to other.

A doubly fed induction machine is basically a standard, wound rotor induction machine with its stator windings directly connected to the grid and its rotor windings connected to the grid and its rotor windings connected to the grid through a converter. The AC/DC/AC Converter is divided to two components: the rotor side converter and the grid side converter. These converters are voltage sourced converters that use force commutated power electronic devices to synthesize an AC Voltage from a DC source. A capacitor connected on the DC side acts as the DC voltage source. A coupling inductor is used to connect the grid side converter to the grid. The three phase rotor
winding is connected to the rotor side converter by slip rings and brushes and the three phase stator windings are directly connected to the grid. The control system generates the pitch angle command and the voltage command signals $V_r$ and $V_{gc}$ for the rotor and grid side converters respectively in order to control the power of the wind turbine, the DC voltage and the reactive power or the voltage at the grid terminals [13].

![Basic diagram of Doubly fed induction generator with converters](image)

**Fig. 1: Basic diagram of Doubly fed induction generator with converters**

### III. POWER FLOW OF DFIG

Figure 2 shows the Power flow in a DFIG. Generally the absolute value of slip is much lower than 1 and consequently the rotor electrical power output $P_r$ is only a fraction of stator real power output $P_s$. Since the electromagnetic torque $T_m$ is positive for power generation and since $W_s$ is positive and constant for a constant frequency grid voltage, the sign of $P_r$ is a function of the slip sign. $P_r$ is positive for negative slip (speed greater than synchronous speed) and it is negative for positive slip (speed lower than synchronous speed). For super synchronous speed operation, $P_r$ is transmitted to DC bus capacitor and tends to raise the DC voltage. For sub synchronous speed operation, $P_r$ is taken out of the DC bus capacitor and tends to decrease the DC bus voltage. The grid side converter is used to generate or absorb the grid electrical power $P_{gc}$ in order to keep the DC voltage constant. In steady state for a lossless AC/DC/AC converter $P_{gc}$ is equal to $P_r$ and the speed of the wind turbine is determined by the power $P_r$ absorbed or generated by the rotor side converter. By properly controlling the rotor side converter, the voltage measured at the grid terminals can be controlled by controlling the grid side converter DC bus voltage of the capacitor can be regulated.

![Power flow diagram of DFIG](image)

**Fig. 2: Power flow diagram of DFIG**

The principles of operation of doubly-fed induction generators, it can thus be determined that, when the magnetic field at the rotor rotates in the same direction as the generator rotor, the rotor speed $n_{rotor}$ and the speed $n_{\phi, rotor}$ of the rotor magnetic field (proportional to $f_{rotor}$) add up. This is shown in Figure. The frequency $f_{stator}$ of the voltages induced across the stator windings of the generator can thus be calculated using the following equation:

$$f_{stator} = \frac{n_{rotor} \cdot n_{\phi, rotor}}{120} + f_{rotor}$$  \hspace{1cm} (3.1)

Where, $f_{rotor}$ is the frequency of the ac currents fed into the doubly-fed induction generator rotor windings, expressed in hertz (Hz).

Conversely, when the magnetic field at the rotor rotates in the direction opposite to that of the generator rotor, the rotor speed $n_{rotor}$ and the speed $n_{\phi, rotor}$ of the rotor magnetic field subtract from each other. This is shown in Figure. The frequency of $f_{stator}$ the voltages induced across the stator windings of the generator can thus be calculated using the following equation:

$$f_{stator} = \frac{n_{rotor} \cdot n_{\phi, rotor}}{120} - f_{rotor}$$  \hspace{1cm} (From 3.1)

**Stator Voltage Equations:**

$$V_{qs} = p\lambda_{qs} + \omega\lambda_{ds} + r_s i_{qs}$$ \hspace{1cm} (3.2)

$$V_{ds} = p\lambda_{ds} - \omega\lambda_{qs} + r_s i_{ds}$$ \hspace{1cm} (3.3)

**Rotor Voltage Equations:**

$$V_{qr} = p\lambda_{qr} + (\omega - \omega_r)\lambda_{dr} + r_r i_{qr}$$ \hspace{1cm} (3.4)

$$V_{dr} = p\lambda_{dr} - (\omega - \omega_r)\lambda_{qr} + r_r i_{dr}$$ \hspace{1cm} (3.5)

**Power Equations:**

$$P_s = \frac{3}{2}(V_{ds} i_{ds} + V_{qs} i_{qs})$$ \hspace{1cm} (3.6)

$$Q_s = \frac{3}{2}(V_{qs} i_{qs} - V_{ds} i_{ds})$$ \hspace{1cm} (3.7)

**Torque Equations:**

$$T_e = -\frac{3}{2} \frac{p}{2} (\lambda_{ds} i_{qs} - \lambda_{qs} i_{ds})$$ \hspace{1cm} (3.8)

**Stator Flux Linkage Equations:**

$$\lambda_{qs} = (L_{qs} + L_m) i_{qs} + L_m l_{qr}$$ \hspace{1cm} (3.9)

$$\lambda_{ds} = (L_{ds} + L_m) i_{ds} + L_m l_{dr}$$ \hspace{1cm} (3.10)

**Rotor Flux Linkage Equations:**

$$\lambda_{qr} = (L_{qr} + L_m) l_{qr} + L_m i_{qs}$$ \hspace{1cm} (3.11)

$$\lambda_{dr} = (L_{dr} + L_m) l_{dr} + L_m i_{ds}$$ \hspace{1cm} (3.12)
A. Modeling of DFIG

The induction machine can be represented by the transformer per phase equivalent circuit model where \( R_r \) and \( X_r \) represent rotor resistance and reactance referred to the stator side. The primary internal stator induced voltage \( E_{st} \) is coupled to the secondary rotor induced voltage \( E_r \) by an ideal transformer with an effective turn ratio \( a_{eff} \). But the equivalent circuit of Fig. 4 differs from the transformer equivalent circuit primarily in the effects of varying rotor frequency on the rotor voltage \( E_r \). In the case of doubly fed induction machines, however, there is a voltage injected into the rotor windings so that the normal induction machine equivalent circuit of Fig. 4 needs to be modified by adding a rotor injected voltage as shown in Fig. 5.

From the equivalent circuit, for a doubly fed induction machine the real and reactive power of stator \( P_{sw} \), \( P_{dq} \) and rotor \( P_{rw}, P_{rq} \) and the torque developed \( T_m \) can be derived as follows

\[
P_{sw} = 3V_1I_1\cos(\Phi_{v1} - \Phi_{i1}) \tag{3.13}
\]
\[
P_{dq} = 3V_1I_1\sin(\Phi_{v1} - \Phi_{i1}) \tag{3.14}
\]
\[
P_{rw} = 3V_2I_2\cos(\Phi_{v2} - \Phi_{i2}) \tag{3.15}
\]
\[
P_{rq} = 3V_2I_2\sin(\Phi_{v2} - \Phi_{i2}) \tag{3.16}
\]
\[
T = 3E_{st}I_r\sin(\Phi_{st} - \Phi_{i2}) \tag{3.17}
\]

Where, \( V_1, I_1 \) and \( V_2, I_2 \) are the effective (RMS) values of the stator and rotor voltage and current respectively.

B. Simulation of DFIG

In this a simulation of DFIG is carried out using MATLAB & the results are taken for voltage, current, power, wind speed etc.

<table>
<thead>
<tr>
<th>Generator Type</th>
<th>DFIG Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated Mechanical Power</td>
<td>5 Mw 1pu</td>
</tr>
<tr>
<td>Rated Stator Line to Line Voltage</td>
<td>950 V(rms)</td>
</tr>
</tbody>
</table>

| Rated Stator phase Voltage | 548.48 V(rms) 1pu |
| Rated Rotor phase Voltage | 381.05 V(rms) 0.6947pu |
| Rated Stator Current | 2578.4 A(rms) 0.8485pu |
| Rated Rotor Current | 3188.7 A(rms) 1.0494pu |
| Rated Stator Frequency | 50Hz 1pu |
| Rated Rotor Speed | 1170 rpm 1pu |
| Nominal Rotor Speed Range | 670-1170 rpm 0.573-1pu |
| Rated Slip | -0.17 |
| Number of Pole Pairs | 3 |
| Rated Mechanical Torque | 40.809 KN-m 1pu |
| Stator Winding Resistance, \( R_s \) | 1.552mΩ 0.0086pu |
| Rotor Winding Resistance, \( R_r \) | 1.446mΩ 0.008pu |
| Stator Leakage Inductance, \( L_{ls} \) | 1.721mH 2.2141pu |
| Rotor Leakage Inductance, \( L_{lr} \) | 1.194mH 1.9483pu |
| Magnetizing Inductance, \( L_m \) | 5.5182mH 9.6044pu |
| Base Current \( I_B \) | 3038.7A(rms) 1pu |
| Base Flux Linkage | 1.7459Wb(rms) 1pu |
| Base Impedance | 0.1805Ω 1pu |
| Base Inductance | 0.5746mH 1pu |
| Base Capacitance | 17634.9µF 1pu |

Table 1: DFIG Parameters

Due to fault after 5 sec time delay all the generator will trip and so we get zero output.
IV. RESULTS & CONCULATION

For this the DFIG can work at variable speed; it gives the optimum output at respective speed, but induction generator can work at fixed speed. The Output power is more reliable in DFIG. In IG capacitor bank or STATCOM is required to compensate the reactive power. In DFIG there is no need of such equipment for compensating the reactive power. DFIG is more stable at Transient Fault condition than IG.

REFERENCES


