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Performance analysis of grid-connected and stand alone wind farm

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Abstract

Wind power plants are becoming popular renewable energy sources in the distribution system, it employs Doubly Fed Induction Generator (DFIG) to generate power based on wind conversion. This paper highlights issues of voltage stability check during various load parameters which include short and long transmission lines in both grid-connection and Islanding scenarios, THD and load fluctuations. Basically this study develops a framework to carryout the investigation on electrical variables and therefore voltage profile between wind stations and load centers are realized. A microgrid based small signal analysis is performed in the laboratory using MATLAB and different comparisons are made and simulation case studies are presented.

Keywords: doubly fed induction generator (DFIG); voltage source converter; voltage stability, THD

1. Introduction

Nowadays, renewable energy usage such as wind energy becomes an important source. This is mainly due to fossil fuel resources reduction worldwide such as oil, coal and etc. Furthermore, the fossil fuels have environment issues such as acid rain, emitting hazardous, green housing effect etc. [1], [2]. Besides that, carbon dioxide (CO2) emissions also present serious health and environmental problems. Harnessing electrical energy from non-conventional energy resources can be cheaper and more convenient compared with grid connection particularly in remote areas which incorporate costly transmission line set up and power losses. Wind farm based distributed generations have gained wide attention in recent years as strong candidate of an efficient energy source particularly in rural local communities. Wind farm has already gained popularity in Europe where the total capacity if installed wind turbine generator systems is continuously increasing which most of them are located in Germany, and Spain energy policy has determined to archive 60,000 MW in year 2010 and in 2020, 150,000 MW of installed wind power [1], [3]. Most of actual wind farms in Spain are in fact made up of several wind turbines installed in one site operating almost independently of each other. Lately wind farms employed simple squirrel cage induction generators (SSCIG) that operate at a speed that is substantially constant and as a consequence of this are normally referred to as fixed speed induction generators. But the chief disadvantage of this SSCIG is poor/Limited control capability; therefore the use of a DFIG on a wind turbine has gained more attention. It improves the efficiency of energy transfer from the wind but also provides wind farms with the capability of contributing significantly to network support and operation with respect to voltage control, transient performance, and damping. DFIG has the capability of manipulating both the magnitude and the position of the rotor flux vector and consequently it possesses a much greater control capability than the later type of induction generator.

2. Model Description of DFIG System

Basically, wind turbines driven on doubly-fed induction generator (DFIG) consist of wound rotor

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Induction generator and also AC/DC/AC IGBT-based PWM converter which can be seen in Fig. 2.2. This is where the stator winding is connected directly to 50 Hz grid while the rotor part is fed at variable frequency through the AC/DC/AC converter. By optimizing the turbine speed, the DFIG technology allows extracting maximum energy from the wind for low wind speeds, while minimizing mechanical stresses on the turbine during gusts of wind. The optimum turbine speed producing maximum mechanical energy for a given wind speed is proportional to the wind speed [4]. Another advantage of the DFIG technology is the ability for power electronic converters to generate or absorb reactive power, thus eliminating the need for installing capacitor banks as in the case of squirrel-cage induction generator [4].

Based on Fig. 1, V_r is referring to the rotor voltage while V_{gc} represents grid side voltage. The presence of harmonics in wind turbine of DFIG system can be minimized since AC/DC/AC converter is a PWM converter where it uses sinusoidal PWM technique. It contains, Fig. 2.1, C_{grid} which refers to grid side converter and C_{rotor} is rotor side converter. In order to control the speed of wind turbine, electronic control based gear box is employed. The doubly-fed generator rotors are typically wound with from 2 to 3 times the number of turns of the stator, which mean the rotor voltages higher and currents respectively lower [5].

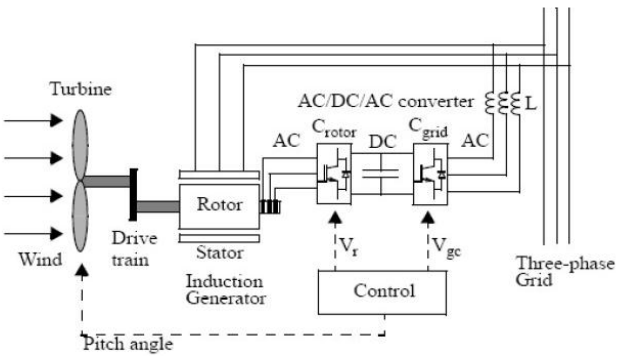


Fig. 1. Basic diagram of Double Fed Induction Generator (DFIG) with converter [4].

Thus in the typical ± 30 % operational speed range around the synchronous speed the rated current of the converter is accordingly lower leading to a low cost of the converter [5]. The drawback is that controlled operation outside the operational speed range is impossible because of the higher than rated rotor voltage [5].

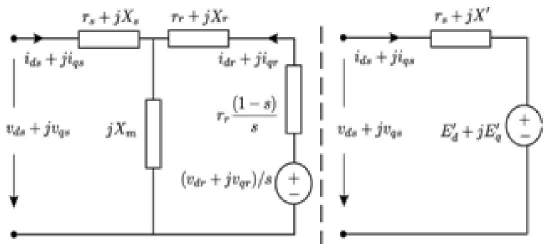


Fig. 2. Steady-state and dynamic equivalent circuit of DFIG [6]

Figure 1 also shows a typical scheme of a DFIG equipped wind turbine. Two voltage fed PWM converters are inserted back-to-back in the rotor circuit, which connect the slip ring terminals to the ac supply network. By adjustment of the switching of the Insulated Gate Bipolar Transistors in both converters, the power flow between the rotor circuit and the supply can be controlled both in magnitude and in direction [6], [7], [8], [9]. This is effectively the same as connecting a controllable voltage source to the rotor circuit [10]. The DFIG can be regarded as a traditional induction generator with a nonzero rotor voltage. With the stator transients neglected, per unit electrical equations of the DFIG can be written in phasor form as follows [10], [11].

E'	Voltage behind the transient impedance
H_r , H_m	Generator rotor and wind turbine shaft inertia
i	Current
L	Inductance
$\omega_s, \Omega_m, \Omega_r$	Synchronous, wind turbine shaft, and generator rotor angle speed
ψ	Flux linkage
P, Q	Active and reactive power
r	Resistance
s	Rotor slip
$\theta_s, \theta_m, \theta_r$	Terminal voltage, wind turbine shaft and generator rotor angle position
T_0'	Rotor circuit time constant
T_{em}	Electromagnetic torque
T_m	Mechanical torque act on the generator rotor
T_ω	Wind turbine prime torque from wind
v	Voltage
V_ω	Wind speed
X, X', X_m	Steady-state, transient, and magnetizing reactance
	Symbols
Δ	Deviation from normal value
	Suffices, Superscripts
d, q	Direct and quadrature axis components
s, r	Generator's stator and rotor components
'	Transient state component

Stator voltage

$$v_{ds} = r_s i_{ds} + \omega_s \psi_{qs} \quad (1)$$
$$v_{qs} = r_s i_{qs} + \omega_s \psi_{ds} \quad (2)$$

Rotor voltage

$$v_{dr} = r_r i_{dr} - s\omega_s \psi_{qr} + \frac{d\psi_{dr}}{dt} \quad (3)$$
$$v_{dr} = r_r i_{qr} - s\omega_s \psi_{dr} + \frac{d\psi_{qr}}{dt} \quad (4)$$

Flux linkage

$$\psi_{ds} = -L_{ss} i_{ds} + L_m i_{dr} \quad (5)$$
$$\psi_{qs} = -L_{ss} i_{qs} + L_m i_{qr} \quad (6)$$
$$\psi_{dr} = -L_m i_{ds} + L_{rr} i_{dr} \quad (7)$$
$$\psi_{qr} = -L_m i_{qs} + L_{rr} i_{qr} \quad (8)$$

Electromagnetic torque

$$T_{em} = \psi_{qr} i_{dr} - \psi_{dr} i_{qr}$$

Fig. 2 shows the steady-state and dynamic equivalent circuit of the DFIG, respectively. By eliminating the rotor currents,i_{dr},i_{qr}, in electromagnetic torque (9), and when $\omega_s = 1.0pu$, we find

$$T_{em} = E'_d i_{ds} + E'_q i_{qs} \quad (10)$$

The power losses associated with the stator resistance are small enough to ignore, thus approximation of electromagnetic power or torque can be written as

$$T_{em} = P_s = v_{qs}i_{ds} + v_{qs}i_{qs} \tag{11}$$

While the reactive power that the stator absorbs from, or injects into the power system can be calculated as

$$Q_s = v_{qs}i_d - v_{ds}i_{qs} \tag{12}$$

Accordingly, the rotor motion of the DFIG can be written as

$$2H_r \frac{d\Delta\Omega_r}{dt} = -T_{em} - T_m \tag{13}$$

For the case of generators, the value of corresponding to the direction of current and voltage shown in Figure 2.3 is negative. Similarly, the rotor power (also called slip power) can be calculated as

$$P_r = v_{dr}i_{dr} + v_{qr}i_{qr} \tag{14}$$

$$Q_r = v_{qr}i_{dr} - v_{dr}i_{qr} \tag{15}$$

Additionally, the wind turbine shaft system should not be considered stiff, since the generator rotor and wind turbine shaft are coupled together via a gearbox. The shaft motion becomes more complex than the lumped-mass system due to interaction between the rotor and windmill. Hence, to account properly for this effect, an additional equation has been adopted to describe the motion of the windmill shaft [12]

$$2H_m \frac{d\Delta\Omega_m}{dt} = T_m - T_w \tag{16}$$

where the mechanical torque can be represented by the twist angle between the wind turbine shaft and the generator rotor

$$T_m = K_s(\theta_r - \theta_m) \tag{17}$$

Thus, basically, the purpose of back-to-back inverter is to provide a mechanism of converting the variable voltage, variable frequency output of the generator into a fixed frequency, fixed voltage output compliant with the grid [13]. The converter is capable of changing the output voltage almost instantaneously.

3. Test System

In this paper, it is worth to state voltage-current profile and harmonic of load alters during both Grid – connected and stand-alone DFIG. Besides that, the impact present of connected and not connected to grid will be investigated through the performance of voltage and current profile analysis. Thus, a few analysis also will be done on how to improve the harmonic and voltage-current profile through the wind turbine distance with the load receiving, either it is near to load receiving (short transmission line) and far from the load receiving (long transmission line). The analysis also sees the system affected if there is high load, and low load. In this system the power of wind turbine is 9MW consist of six 1.5MW connected to 25kV distribution system exports power to a 154kV grid through a 30km, 25-kV feeder. This wind turbine system is including the induction motor with power electronic IGBT converters. Besides a 100-MW resistive load is connected on the same feeder at bus B25.

4. Result and Discussion

The usage of renewable energy such as wind energy commonly gives the impact to power system stability and also energy power output of the wind turbine. Hence, it is very important to know how the voltage and current profile of the overall of the plantation. Besides, through this studied, it also including how the THD at load receiving affected in the system which is one of the way to figure out how to reduce the THD at load receiving and also having stable voltage and current profile.

Therefore, in this studied, the simulations of the proposed AC voltage control strategy have been obtained using MATLAB Simulink model. 1 MW DFIG capacity is used to supply energy to highly inductive load during grid connection and islanding cases. Thus, through the collected result, the work is classified into various loading condition of simulation with long and short transmission lines classified as 10km and 1km respectively. In each condition, the result simulation will be seen during high load receiving (100MW) and low load receiving (500kW) for both Grid connected wind turbine and Stand-alone wind turbine.

Based on Fig. 3 to Fig. 6, the results validate the superior performance of grid connected wind turbine in term of voltage stability and reliability operation than that in stand-alone system. Harmonic level is also substantially reduced during grid connection. This simulated results show wind power plant is stable during short transmission operation. Simulation results show for short transmission line the system is more stable with less fluctuation.

A. Long Transmission Line (10km)

1) High load (100MW)

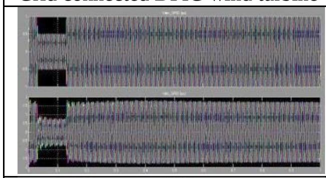
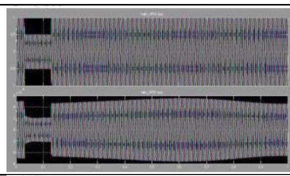
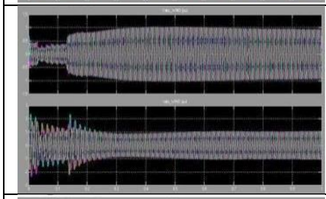
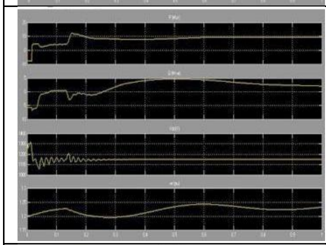
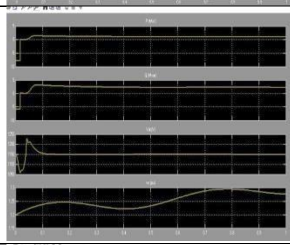
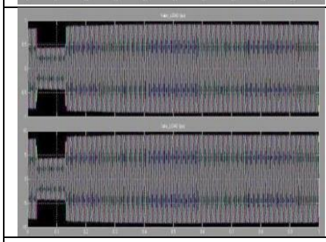
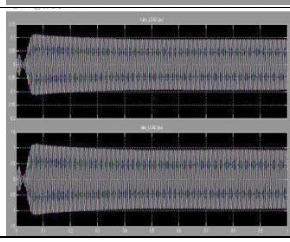
Grid connected DFIG wind turbine		Stand-alone DFIG wind turbine
	(a)	
	(b)	
	(c)	
	(d)	
0.03%	(e)	2.78%

Fig. 3. Comparison result collected for Grid connected and Stand-alone DFIG wind turbine during long transmission (10km) for high load (100MW)

(a) *Voltage and current graph of the Grid respectively;*
(b) *Voltage and Current graph of wind turbine respectively;*
(c) *Graphs of P (MW), Q (MVAR), VDC (V) and w (Pu) respectively;*
(d) *Voltage and current graph of the load respectively;*
(e) *Current total harmonic distortion (THDC) of the load*

2) Low load (500kW)

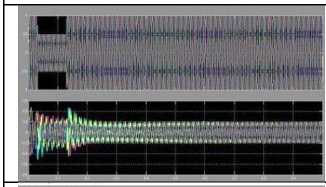
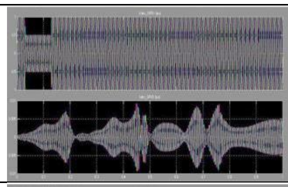
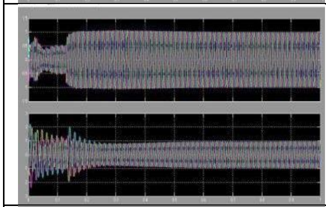
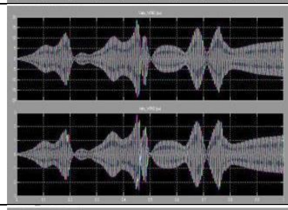
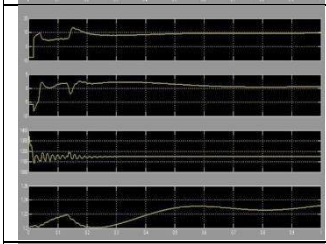
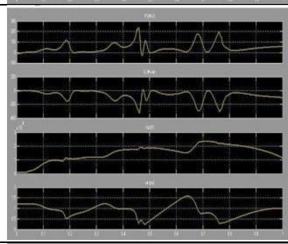
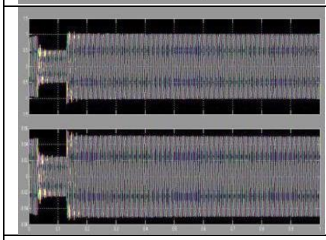
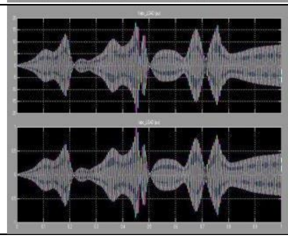
Grid connected DFIG wind turbine		Stand-alone DFIG wind turbine
	(a)	
	(b)	
	(c)	
	(d)	
0.16%	(e)	12.77%

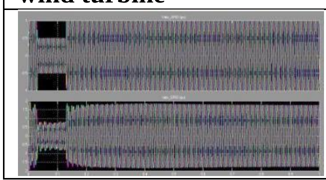
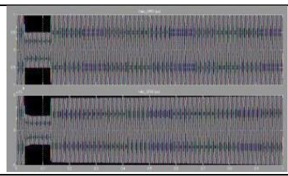
Fig. 4. Comparison result collected for Grid connected and Stand-alone DFIG wind turbine during long transmission (10km) for low load (500kW)

(a) *Voltage and current graph of the Grid respectively;*
(b) *Voltage and Current graph of wind turbine respectively;*
(c) *Graphs of P (MW), Q (MVAR), VDC (V) and w (Pu) respectively;*
(d) *Voltage and current graph of the load respectively;*
(e) *Current total harmonic distortion (THDC) of the load*

B. Short Transmission Line (1km)

1) High load (100MW**)**

Table 4.3 Comparison result collected for Grid connected and Stand-alone DFIG wind turbine during short transmission (1km) for high load (100MW)

Grid connected DFIG wind turbine		Stand-alone DFIG wind turbine
	(a)	

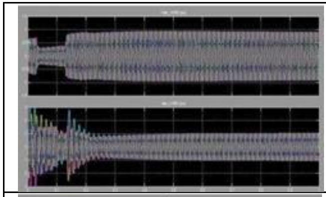
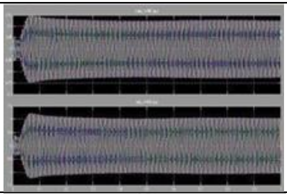
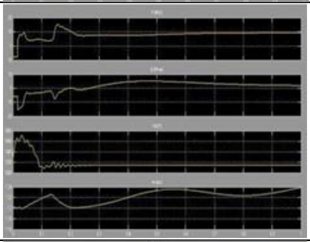
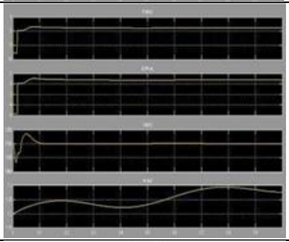
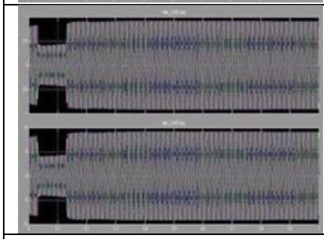
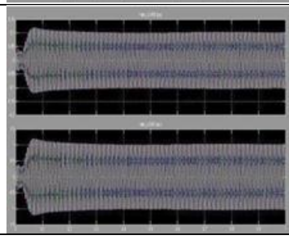
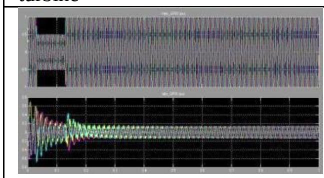
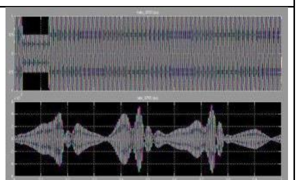
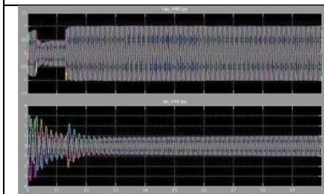
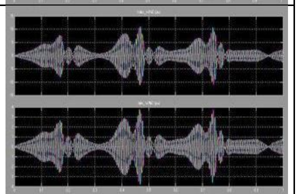
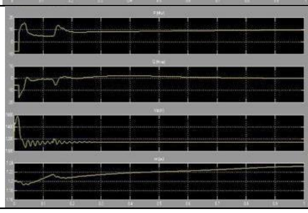
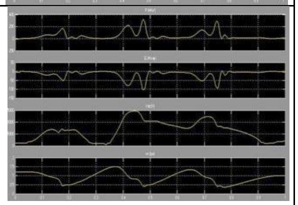
	(b)	
	(c)	
	(d)	
0.03%	(e)	0.49%

Fig. 5. Comparison result collected for Grid connected and Stand-alone DFIG wind turbine during short transmission (1km) for high load (100MW)

(a) *Voltage and current graph of the Grid respectively;*
(b) *Voltage and Current graph of wind turbine respectively;*
(c) *Graphs of P (MW), Q (MVAR), VDC (V) and w (Pu) respectively;*
(d) *Voltage and current graph of the load respectively;*
(e) *Current total harmonic distortion (THDC) of the load*

2) Low load (500kW)

Table 4.4. Comparison result collected for Grid connected and Stand-alone DFIG wind turbine during long transmission (10km) for low load (500kW)

Grid connected DFIG wind turbine		Stand-alone DFIG wind turbine
	(a)	
	(b)	
	(c)	

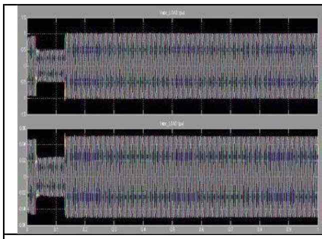
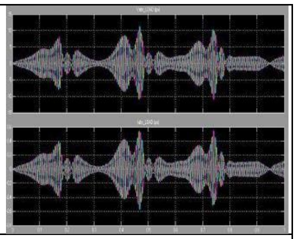
	(d)	
0.05%	(e)	53.30%

Fig. 6. Comparison result collected for Grid connected and Stand-alone DFIG wind turbine during long transmission (10km) for low load (500kW)

***(a)** Voltage and current graph of the Grid respectively;*
***(b)** Voltage and Current graph of wind turbine respectively;*
***(c)** Graphs of P (MW), Q (MVAR), VDC (V) and w (Pu) respectively;*
***(d)** Voltage and current graph of the load respectively;*
***(e)** Current total harmonic distortion (THDC) of the load*

5. Conclusion

This paper proposed the modeling and performance analysis of Grid-connected of wind turbine with doubly fed induction generator (DFIG) system. A comparison between Grid-connected DFIG and stand-alone DFIG through a few cases has been studied. Voltage and current profile of the system are more stable with less fluctuation compared to the stand-alone DFIG. The analysis though out this paper also shows a reduction of total current harmonic with low value of current with condition of high loading compared to low loading. Grid-connection DFIG exhibits stable voltage and current profile when the plant is near to the load short transmission line. In overall cases the proposed model gave valuable insight into the performance of the variable speed wind turbine equipped with a DFIG and the interaction between the wind park and the main system.

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