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ANALYSIS OF WIND FARMS IN A GRID INTERCONNECTION

C. Rohmingtluanga
Mizoram University, Mizoram, India
Rta54321@gmail.com

Abstract — **Due to Increase in fossil fuel prices and climate change the study of renewable energy generation sources is very important. Wind and solar are clean and abundant compare to other sources of energy. Focusing on the wind energy and finding out the performance of different wind turbine combination integrating with the GRID is important. Two wind generator technologies, namely, Doubly-Fed Induction Generator (DFIG), and Converter Driven Synchronous Generator (CDSG) are considered in this paper. The main focus is to study the system response under change in wind speed, voltage sag and faults for different wind turbine performance and comparing DFIG and CDSG for a particular wind farm. MATLAB simulation software package is used for the analysis in this paper.**

Index Terms - **Doubly-Fed Induction Generator (DFIG), Converter Driven Synchronous Generator (CDSG), system response, comparing DFIG and CDSG.**

I. INTRODUCTION

With increase populations and the industrialization of the developing world, more energy is required to satisfy basic needs of the human life and to attain improved standards of human welfare. The structure of the modern power system is becoming highly complex in order to make energy available economically with reduced carbon emission using renewable energy sources.

The grid interaction and impacts of the wind turbines have been the focus of research over the years. There have been concerned about the intermittence nature of the power generated from wind turbines. These concerns are also the limiting factors to further increase the integration of wind power. However, recent studies have shown that these concerns may not be founded

In this paper, the impacts of the combination of different wind turbines in a single farm are considered. Two variable speed wind generator technologies Doubly-Fed Induction Generator (DFIG) and Converter Driven Synchronous Generator (CDSG) are used. The impacts of the combination of turbines in a single farm under change in wind speed and system voltage variations are investigated.

I.WIND GENERATORS

1. Doubly Fed Induction Generator (DFIG)

Doubly-Fed Induction Generator (DFIG) is one of the most generator used for generating power in the wind farms today. The turbine rotor and the generator is connected by a gear box. The generator is connected to the grid through a three-winding transformer. The stator winding of the generator is connected directly to the power grid. The rotor winding is connected via frequency converter and the accompanying power transformer as shown in Figure.1 below One of the advantages of the DFIG is that real power and reactive power can be controlled separately, it can be operated under sub-synchronous and/or super-synchronous mode of operations.

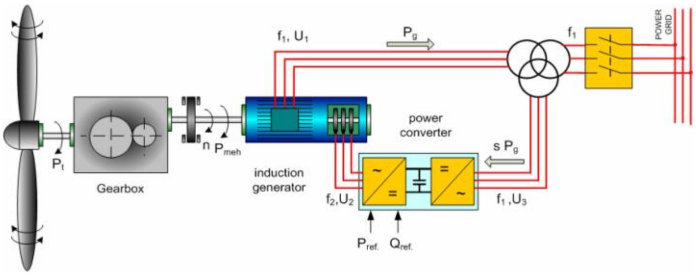

Fig.1 Doubly-Fed Induction Generator (DFIG)

The main reason for using a doubly-fed induction generator is synchronous operation, which is to produce three-phase voltage whose frequency f_{stator} is constant, i.e. the stator frequency f_{stator} remains equal to the frequency $f_{network}$ of the ac power network to which the generator is connected, despite variations in the generator rotor speed f_{rotor} caused by fluctuations of the mechanical power provided by the prime mover (e.g. a wind turbine rotor) driving the generator.

In conventional (singly-fed) induction generators, the relationship between the frequency f_{stator} of the ac voltages induced across the stator windings of the generator and the rotor speed n_{rotor} is expressed using the following equation.

$$f_{stator} = \frac{n_{rotor} \times N_{poles}}{120} \qquad (1)$$

The same operating principles apply in a doubly-fed induction generator as in a conventional (singly-fed) induction generator. The only difference is that the magnetic field created in the rotor is not static (as it is created using three-phase ac current instead of dc current), but rather rotates at a speed

$n_{\emptyset,rotor}$ proportional to the frequency of the ac currents fed into the generator rotor windings. Taking into account 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 $n_{\emptyset,rotor}$ of the rotor magnetic field (proportional to f_{rotor}) add up. The frequency f_{stator} of the voltages induced across the stator windings of the generator can thus be calculated using the following equation

$$f_{stator} = \frac{n_{rotor} \times N_{poles}}{120} + f_{rotor} \qquad (2)$$

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 $n_{\emptyset,rotor}$ of the rotor magnetic field subtract from each other. The frequency f_{stator} of the voltages induced across the stator windings of the generator can thus be calculated using the following equation.

$$f_{stator} = \frac{n_{rotor} \times N_{poles}}{120} - f_{rotor} \qquad (3)$$

In other words, the frequency f_{stator} of the ac voltages produced at the stator of a doubly-fed induction generator is proportional to the speed $n_{\emptyset,stator}$ of the rotating magnetic field at the stator. The speed $n_{\emptyset,stator}$ of the stator rotating magnetic field itself depends on the rotor speed n_{rotor} (resulting from the mechanical power at the rotor shaft) and the frequency f_{rotor} of the ac currents fed into the machine rotor.

The frequency f_{rotor} of the ac currents that need to be fed into the doubly-fed induction generator rotor windings to maintain the generator output frequency f_{stator} at the same value as the frequency $f_{Network}$ of the ac power network depends on the rotation speed of the generator rotor n_{rotor}, and can be calculated using the following equation:

$$f_{rotor} = f_{network} - \frac{n_{rotor} \times N_{poles}}{120} \qquad (4)$$

Using Equation (4), it is possible to calculate that, if the generator rotor rotates at the nominal (singly-fed) synchronous speed n_s, the frequency f_{rotor} of the ac currents that need to be fed into the generator rotor windings will be equal to 0 Hz (i.e., dc current). The machine would thus operate as a conventional (singly-fed) three-phase synchronous machine.

2. Converter Driven Synchronous Generator(CDSG)

Converter Driven Synchronous Generator (CDSG) is generally used in large conventional power plants. The generator can be excited electrically (i.e., wound rotor synchronous generator-WRSG) or by permanent magnet synchronous generator (PMSG). Similarly to the DFIG, it has a gearbox connected between the turbine rotor and generator. The generator is connected to the grid through a back-to-back full converter as shown in figure 2. The converter can be either voltage source or diode rectifier to enable variable speed operation. The electrical frequency of the generator may vary as the wind speed changes but the network frequency is not influenced by the wind speed, this is because the converter completely decouples the generator from the network.

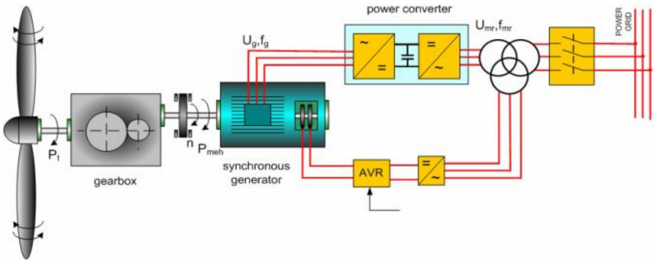

Fig.2 Converter Driven Synchronous Generator (CDSG)

Permanent magnet machines have usually a higher efficiency and are more compact than electrically excited machines. However, they are still considerably more expensive and require more advanced rectifiers because they don't allow for reactive power or voltage control. For allowing variable speed operation, the synchronous generator must be connected to the grid through a frequency converter. The generator is connected to an intermediate DC-circuit by a diode rectifier. The grid-side connection is realized by a self commutated pulse-width modulated (PWM)-converter that imposes a pulse-width modulated voltage to the AC-terminal. The PWM converter is connected to the network through a filter, The level of harmonics in the voltage at the connection point is extremely low.

The wound rotor synchronous generator is already being used as a wind power turbine generator, but one of the major disadvantage of a synchronous generator can be its complexity and cost. Gearless direct drive generators are very slow turning synchronous generators with large numbers of poles in order to reach their synchronous speed. Generators with fewer poles have higher rotational speeds so require a gearbox or drive train adding to the cost.

Grid-tied generators require a constant fixed speed to synchronize with the utility grid frequency and it is necessary to excite the rotor winding with an external DC supply, using slip rings and brushes. The major disadvantage of one fixed-speed operation is that it almost never captures the wind energy at the peak efficiency. The wind energy is wasted when the wind speed is higher or lower than the certain value selected as the synchronous speed.

Variable speed wind turbines use rectifiers and inverters to convert variable voltage, variable frequency output of the synchronous generator into the fixed voltage, fixed 50Hz or 60Hz frequency output required by the utility grid. This allows for permanent magnet synchronous generators to be used reducing the cost. For low speed direct drive wind turbine generators the permanent magnet generator is more competitive because it can have higher pole number of 60 or more poles compared to a conventional wound rotor synchronous generator.

II. PROPOSED SYSTEM MODEL

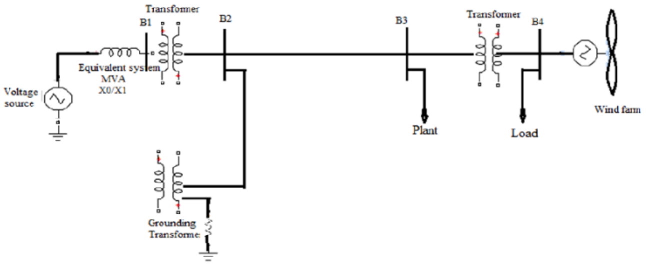

Fig. 3 Single line diagram of the proposed system.

The above diagram shows the single line diagram consisting two sources the voltage source (Generator) and the wind farm (DFIG or CDSG). Connected together through a line consisting a plant and a load. The block diagram shows four buses B1, B2, B3 and B4 along the line. Two star-delta Transformers are used in this block diagram step down transformer for the Generator side and Step up Transformer for the Wind farm and the Grounding Transformer is provided for the neutral point in a three wire system.

The wind farm consists of six 1.5 MW which has a total combination of 9 MW wind turbines connected to a 25 kV distribution system exporting power to a 120 kV grid through a 30 km 25 kV feeder. A 2300V, 2 MVA plant consisting of a motor load (1.68 MW induction motor at 0.93 PF) and of a 200 kW resistive load is connected on the same feeder at bus B25. A 500 kW load is also connected on the 575 V bus of the wind farm Voltage, current and machine speed are monitored.

III. SIMULATION TOOLS

Simulink model are divided into two parts:
1. DFIG simulation System response.
2. CDSG Simulation System response.

The simulation is performed for both DFIG and CDSG for a remote fault on the 120 kV system for a short period of time starting from 0.03 sec using MATLAB simulation software package, and the system response for both turbines are observed. The wind generator data are shown in the following table for both DFIG and CDSG.

s.no	Parameters	Value
1.	Nom. power, L-L volt. and freq. [Pn(VA), Vn(Vrms), fn(Hz)]:	6*1.5e6/0.9 575 60
2.	Stator [Rs,Lls] (pu)	0.00706 0.171
3.	Rotor [Rr',Llr'] (pu)	0.005 0.156
4.	Magnetizing inductance Lm (pu)	2.9
5.	Inertia constant, friction factor, and pairs of poles [H(s) F(pu) p]	5.04 0.01 3
6.	Initial conditions [s() th(deg) Is(pu) ph_Is(deg) Ir(pu) ph_Ir(deg)]	0.2 0 0 0 0 0

Table 1. DFIG Wind Generator data

s.no	Parameters	Value
1.	Nom. power, L-L volt. and freq. [Pn(VA), Vn(Vrms), fn(Hz)]:	6*1.5e6/0.9 575 60
2.	Reactances [Xd Xd'Xd"XqXq"Xl] (pu)	1.305, 0.296, 0.252, 0.474, 0.243, 0.18
3.	Time constant [Tdo'Tdo"Tq"] (s)	4.49 0.0681 0.0513
4.	Resistance Rs (pu)	0.006
5.	Inertia constant, friction factor, and pairs of poles [H(s) F(pu) p]	0.62 0.01 1
6.	Initial conditions [s() th(deg) Is(pu) ph_Is(deg) Ir(pu) ph_Ir(deg)]	0.2 0 0 0 0 0

Table 2. CDSG wind generator data

1. DFIG simulation system response.

The steady-state operation of the DFIG and its dynamic response to voltage sag resulting from a remote fault on the 120-kV system is seen from the figure. Fault is Programmed at t=0.03 s. The DFIG wind farm produces 9 MW. The corresponding turbine speed is 1.2 pu of generator synchronous speed. The DC voltage is regulated at 1150 V and reactive power is kept at 0 Mvar. At t=0.03 s the positive-sequence voltage suddenly drops to 0.5 p.u. causing an oscillation on the DC bus voltage and on the DFIG output power. During the voltage sag the control system tries to regulate DC voltage and reactive power at their set points (1150 V, 0 Mvar). The system recovers in approximately 4 cycles. The system response is shown in the Fig.4 below.

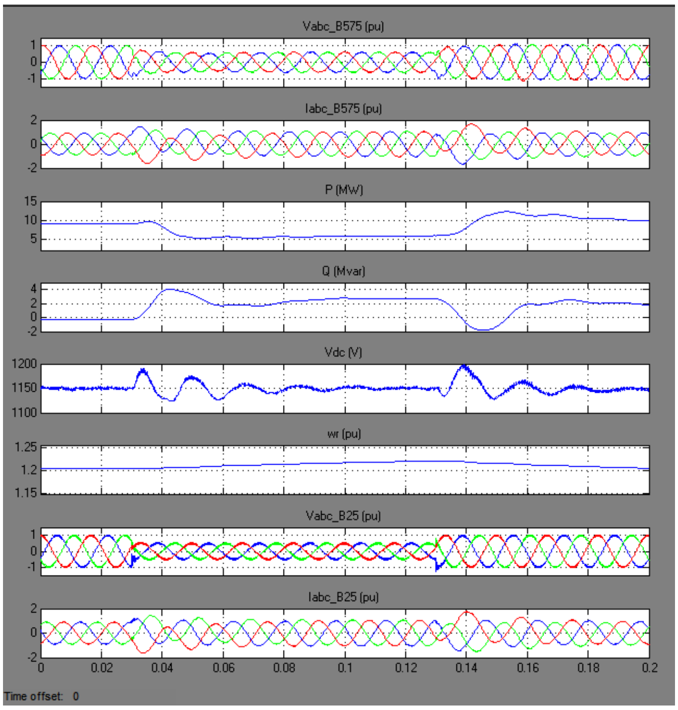

Fig. 4 DFIG simulation system response

2. CDSG Simulation System response.

The steady-state operation of the CDSG wind turbine and its dynamic response to voltage sag resulting from a remote fault on the 120-kV system. The voltage drop is programmed at t=0.03 s. Initially the wind farm produces 9 MW. The corresponding turbine speed is 1 p.u of generator synchronous speed. The DC voltage is regulated at 1100 V and reactive power is kept at 0 Mvar. At t=0.03 s the positive-sequence voltage suddenly drops to 0.75 p.u. causing an increase on the DC bus voltage and a drop on the wind turbine output power. During the voltage sag the control systems try to regulate DC voltage and reactive power at their set points (1100 V, 0 Mvar). The system recovers after fault elimination. The system response is shown in the Fig.5 below.

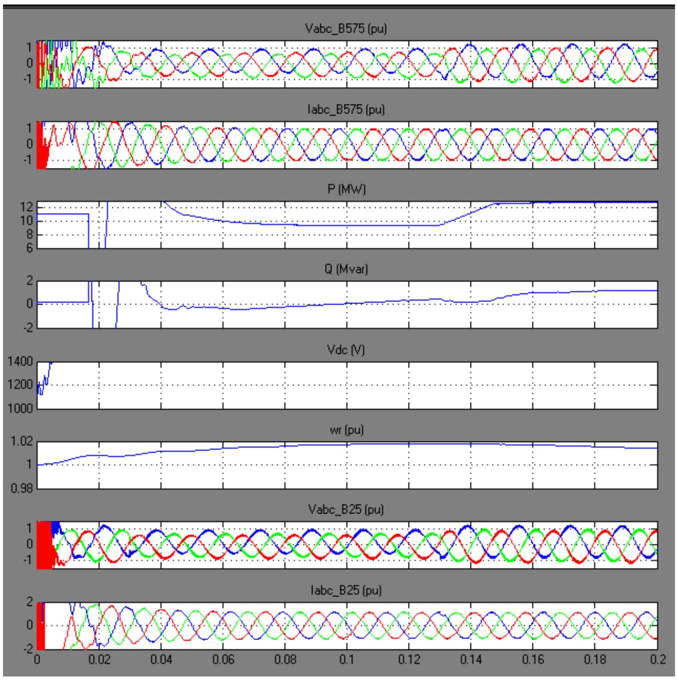

Fig. 5 CDSG Simulation System response.

IV. CONCLUTION

The change in wind speed does not affect much of the system output voltage and frequency, 9 MW power is obtained after the change in wind speed. Voltage sag in the system results in change in Voltage, current and the output Power of the turbine, resulting the system to trip and operate the wind turbine alone for a period of time till the fault is cleared.

From the simulation results presented in this paper the following conclusions can be drawn: The integration of DFIG seems affect the steady-state voltage level in a positive way. Overall, CDSG is seen to give a better performance than DFIG. In particular, during fault and after the fault is cleared.

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