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Operation and Control of a Micro Grid Fed from Large Wind Farm With and Without Energy Storage System Connected to Main Grid

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Key words: DFIG, energy storage system, microgrid, wind energy system, power, control

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Abstract: This study presents, in microgrid system, it is difficult to ensure the loads reliable power supply. The micro grid-wind energy system with and without energy storage connected to Doubly Fed Induction Generator (DFIG) is used to interchange the controllable real and reactive power in the grids and to maintain the quality of power, control and operation at the Point of Common Coupling (PCC). The proposed control methods derived for (DFIG'S) Doubly Fed Induction Generator, energy storage systems. This method is used to maintain quality of power. The system can also be operated as a standalone system in case of grid failure like a uninterrupted power supply. The system studies are made on MATLAB/ Simulink.

INTRODUCTION

Due to heavy population and economic growth the demand for energy is continuously increasing in the world there is a very high demand for energy. Of all the renewable sources wind and solar power generation has become popular. At present, the capacity of the wind power in the world is >40 GW. The combination of energy storage system and micro grids with wind generating system in distributed power system can provide the effective, reliable and durable power system. As the penetration of renewable energy increases, the intermittent nature of renewable energy develops a larger problem demanding the central generation to provide the back-up energy to the system[1]. This increases both the stability problems and also the grid losses and (DG) and storage can provide the required back-up energy with minimum losses. There are several techniques. The variability of power from renewable sources and the variation of loads lead to frequency and voltage problems that may lead to instability of the microgrid. Instead of those techniques (DFIG) Doubly Fed Induction Generator has become most popular[2]. The stator of DFIG is directly connected to the grid and its rotar is also connected to grid through Power Eelectronics Converters (PEC) that is the Rotar Side Converter (RSC) and Stator Side Converter (GSC).

Micro grids are very useful to customers through providing uninterruptible power, enhancing local reliability, reducing transmission loss and supporting local frequency and voltage. To get this, each component must react to local information such as frequency and voltage to correctly vary its operating point. A helpful way to achieve local control without fast-centralized communication is to control active and reactive power injection to/from each component utilizing frequency and voltage droops[3]. One may encounter major problem whenever the wind generators are connected to a weak system or a distributor feeder. Energy Storage (ES) systems are one of the techniques for overcoming the intermittency and the short term varying nature associated with wind energy generation. Integration of the Energy

Storage (ES) system into wind energy generation has many advantages in the power system such as smoothing the wind power fluctuations through absorbing its higher frequencies, controlling the active power balance, providing spinning reserve in order to support the local grid frequency control[4]. During low system voltages, the low voltage ride-through capability serves as power sink. This study introduces operation and control of a microgrid fed from large wind farm with and without Energy Storage Systems (ESS) connected to main grid.

To support the grid frequency in a (Direct Stator Flux Orientation) DSFO-controlled DFIG, a reserve active power is available by operating below the (Maximum Power Point) MPPT, normally referred to as "deloading". This can be achieved by pitch control ands torque control (i.e., inertial energy storage).

MATERIALS AND METHODS

System description: Figure 1 shows the circuit diagram connections of 20 kV local feeder used to investigate possible microgrid operation. In this system multiple DFIGS with the rated capacity of 0.66 and 0.34 p.u are used to connect to grid with and without energy storage systems with the rated capacity. The Energy Storage (ES) that is battery is keeping up in order to control the system. Each and every ES system has an energy capacity limit. It is necessary to make sure that the energy level of the ES does not exceed the maximum limit, nor approach zero level. As a result, in any ES control method, an Energy Management System (EMS) is required to avoid the ES from saturation. The Auxiliary Generation (AG) can also be a long-term energy store (e.g., a fuel cell) and can also be a controlled to import from an external grid. The study, therefore, covers the microgrid and the case when the grid connection is via. a controlled converter.

Model of wind turbine with doubly fed induction generator: The mathematical model of Wind Generator (WG) with DFIG is given[5, 6]:

$$\frac{X'_s}{\omega_s}.\frac{di_{ds}}{dt} = v_{ds} - \left[R_s + \frac{1}{\omega_{sT'_o}\left(X_s - X'_s\right)}\right].i_{ds} - (1-S_r)E'_d - \frac{L_m}{L_{rr}}.V_{dr} + \frac{1}{\omega_{sT'o}}.E'_q + X'_s.i_{qs} \quad (1)$$

$$\frac{X'_s}{\omega_s}.\frac{di_{qs}}{dt} = v_{qs} - \left[R_s + \frac{1}{\omega_{sT'_o}\left(X_s - X'_s\right)}\right].i_{qs} - (1-S_r)q - \frac{L_m}{L_{rr}}.V_{qr} + \frac{1}{\omega_{sT'o}}.E'_d + X'_s.i_{ds} \quad (2)$$

$$\frac{dE'_d}{dt} = S_r\omega_s E'_q - \omega_s.\frac{L_m}{L_{rr}}.V_{qr} - \frac{1}{T'_O}.\left[E'_d + \left(X_s - X'_s\right)i_{qs}\right] \quad (3)$$

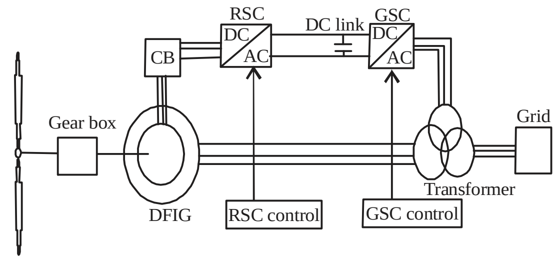

Fig. 1: Schematic representation of proposed control approach

$$\frac{dE'_q}{dt} = S_r\omega_s E'_d - \omega_s.\frac{L_m}{L_{rr}}.V_{dr} - \frac{1}{T'_O}.\left[E'_q + \left(X_s - X'_s\right)i_{ds}\right] \quad (4)$$

Where:

R_S and R_r	=	The stator and rotor phase resistances
L_s and L_r	=	M stator and rotor per phase winding and magnetizing inductances
ω = P	=	The electrical speed and
P	=	The pair pole number

Control of DFIG using direct stator flux orientation: The vector control scheme for a grid connected DFIG is also known as direct stator flux orientation. In this method the stator flux is decided by grid voltage. Controlling the voltage and frequency of an autonomous grid (or microgrid), assisted by short-term Energy Storage (ES), Auxiliary Generation (AG) and Dispatch able Loads (DL)[1, 4]. This method is commonly used for reference frame to analysis and design of control strategy for the DFIG. In the stator-flux orientation frame the d-axis of the reference frame is aligned along the stator-flux space vector that means that q-axis flux linkage is zero and d-axis flux linkage is constant.

Pitch angle control: The pitch angle β is a sum of three parts which are $\beta^* = \beta_{Pes}+\beta_{Ees}+\beta_{max}$ as shown Fig. 2. Besides the DFIG and its control circuit there are three other sources; These are Auxiliary Generation (AG), Dispatch able Loads (DL) and Energy Storage (ES) device and its control circuit. If the captured wind energy is higher than the threshold of ES device then DL is turned on. If the pitch control is slow, the energy absorbed by DL is large. The normal pitch angle control rate is called slew rate which usually is 5^0/sec a rate equal to or larger than slew rate makes DL unnecessary[7]. The AG supplies the mismatch between the wind power and power demanded. In case the wind power is higher than the power demanded then the excess wind power can be shared either by pitch control or by DL. The dynamics of DL, AG and ESS are rather complicated are not touched here. The β_{max} is used to keep the outer power around

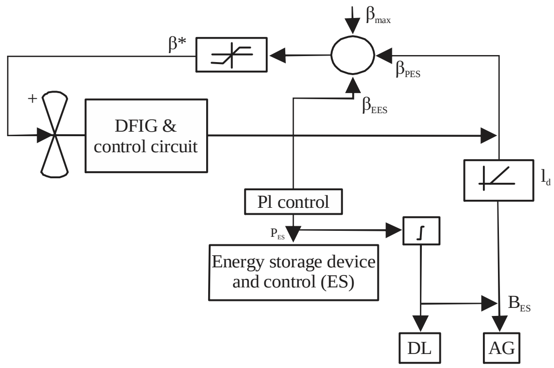

Fig. 2: The pitch angle control and torque control for DFIG and its control circuit

1.0 p.u and to limit the shaft speed to 1.3 p.u. the three parts of $^{\beta}$ are selected in such a way that their sum does not causes a very fast control of pitch angle that affects the power balance.

Torque control: The electrical torque of the DFIG is effectively $T_e = P_g/\omega_r$ where P_g is the generator power (equal to $P_{es}+P_L$) and (ω_r) is shaft speed. The DFIG controls the grid voltage and therefore the real power P_{es} is equivalent to I_d-es, thus, torque is controlled by regulating I_{ES}. Let the reference torque T_e be selected to track the maximum wind power. So that, $T^*_e = k_{opt}\omega^2$ r wind turbine is constant[8]. The torque generated by DFIG is $T_e = 3(\rho/2)\ L_0 i_{ms}.i_{qr}$. Let us assume a rotating frame with the d-axis fixed to the grid voltage can be written as:

$$P_{es} = \frac{3}{2}\left(V_{gd}I_{d\text{-}es}+V_{gq}I_{q\text{-}es}\right) = 3/2V_{gd}I_{d\text{-}es} \quad (5)$$

Substituting Eq. 1 and $T_e = P_g/\omega_r$ P_g into $P_{es}+P_l$ and simplified:

$$T_e = \frac{3}{2}\left(I_{(d\text{-}es)}+P_L/V_{gd}\right)V_{gd}/\omega_r) \quad (6)$$

The current flowing through the ES inductor/transformer inductance L_T and resistance R_T is controlled by inner current loop. The load power is a P_L with external disturbance and can be neglect to the control design. The voltage of grid is maintained constant and as well as controlled by the DFIG. Therefore, the control plant is a variable gain that varies with only ω_r. Due to the rotor inertia ω_r varies smoothly. Hence, it is expected that also varies quite smoothly[3] (Fig. 3).

Variable droop control: The wind speed of DFIG2 drops to 9 m sec^{-1} for 12.5 m sec^{-1}. The DFIG1, however, remains unchanged. Droop control is implemented for various DFIGs. The grid frequency of a DFIG is inversely proportional to the output power of the DFIG. As such the input power to the droop control is no longer a shared component of the load power but is influenced by the available wind power and energy storage power[9]. A variable droop method has been used to which adjusts the output power of the DFIGs according to their wind power. Increased slew rate brings β fast enough to low rate thus increasing the DFIG power and to prevent AG to come in:

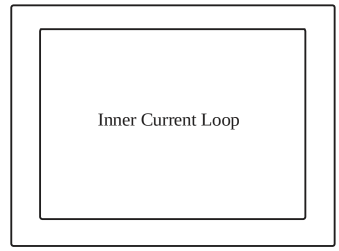

Fig. 3: Electrical torque control layout

$$\Delta E \infty \frac{1}{-R}/2\Delta E = \frac{1}{2}J\left(\omega^2\omega^0\right);$$

change in kinetic energy

$\Delta E \times R$; constant

where, R is the droop coefficient. Let the wind velocity change, so, the wind energy changes by ΔE. With $\Delta E \times R$ is constant, we can find the value of R in variable droop method given the change in the wind energy. The normal droop characteristics $\Delta p_i = -1/R_i(F_{sys}-F_{nom})$:

$$= -1/R_i \Delta F \quad (7)$$

(where, R is the droop of generator I) rearrange Eq. 7 we get = $_{\Delta pi}/F_{sys}-F_{nom}$:

$$= -1/R_i \quad (8)$$

The left hand side of the above equation has the dimensions of energy:

$$\Delta E_i = 1/2J\left(w^2{}_i\text{-}w^2{}_{min}\right)\text{for all i} \quad (9)$$

From Eq. 9 is obtained the following:

$$\Delta E_i.R_i = \text{Constant for all i} = 1, 2, 3 \quad (10)$$

From Eq. 10 indicates that as the wind power change, ΔE varies and the corresponding R can be computed. Because of the inverse relationship between ΔE and R can be written in Eq. 10 as:

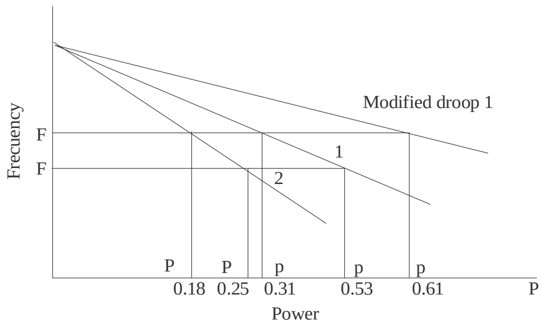

Fig. 4: Variable droop and constant droop curves

$$\text{As}: \Delta E_i.R_i = \Delta E_{max}.R_{min}, \text{ So, } R_i = \Delta E_{max}/\Delta E_i.R_{min}$$

Standard droop control: In a standard droop control, the f-p droop gain is set as m = $\Delta f/p_{nom}$. The maximum frequency deviation is kept the identical for all generators, p_{nom} is the rating of the generator. To examine the importance of the variable droop as given in Fig 4. Two DFIGs are considered to be in parallel both are operating at wind speed of 12.5 m sec^{-1}. The wind speed of the sec DFIG2 is considered to have changed from 12.5 to 9.0 m/sec which resulted in decrease in generated power and consequent decrease in frequency because of the constant load. The wind speed of the DFIG1 is unchanged. The rating of the first DFIG is 0.66 p.u (based on the total wind farm) and that of the second one is 0.34 p.u:

$$p_2^0+p_1^0 = 0.25+0.53 = 0.78 \text{ p.u}$$

$$p_2^1+p_1^1 = 0.18+0.31 = 0.49 \text{ p.u}$$

where, $p_{AG=0}$. If there were no variable droop, then the output power after the reduction in wind speed of DFIG2 will have total droop current = 0.78-0.49 = 0.29 p.u, so, AG takes the balance of power after the disturbance that is equal to 0.78-0.49 = 0.29 p.u. Let the droop of the DFIG1 be controlled as shown in Fig. 4. The total power delivered under the modified droop of DFIG1 = 0.18+0.6 = 0.78 and there is no need for AG to deliver any power.

With Energy Storage Systems (ESS): Use of DFIG for wind power generation is found to be convenient and efficient. Since, it is possible to control the amount of reactive power generated by DFIG, the bus voltage at the Point of Common Coupling (PCC) is stabilized. There are two modes of operation; Grid-connected mode 2. Islanded (autonomous) mode.

Suitable controls for the inverter feeding the rotor of DFIG are to be developed for both these modes of operation. Since, the power available from wind is not predictable the output of DFIG will also vary and to stabilize these power fluctuations suitable energy storage devices (batteries/super capacitors) will be used along with DFIG connected to microgrid. The microgrid takes power from main grid when the load demand is more than the power from wind and battery system. Micro grid also exports power to main grid if it has excesses power, over the load demand.

When the grid is connected, grid provides reference from voltage and frequency for the control of DFIG. When the grid is disconnected for any reason (faults on main system or for maintenance work) the reference signals are taken from PCC.

In this control system, each individual DFIG wind turbine normally consists of two different parts: The electrical control of the DFIG and the mechanical control of the wind turbine blade pitch angle system. Normally controlling of the DFIG can be achieved by controlling the rotar side, Grid side converters and the ESS in Fig. 1. The purpose of the RSC is to regulate the stator side active power P_s and reactive power Q_s independently. The control purpose of the GSC is to maintain the DC-link voltage V_{DC} constant and to regulate the reactive power Q_g that the GSC exchanges with the grid. The control purpose of the ESS is to regulate the active power P_g that the GSC exchanges with the grid. Natural resources, continuously increasing energy demand and aging transmission networks pose many serious problems in power industry. Renewable energy sources such as solar and wind power cannot be integrated directly to the grid. Increasing the penetration of Distributed Generation (DG) in the power system network not only reduces the overall reliability but also increases the complexity of the system. By using renewable generation in combination with Energy Storage Systems (ESS) is one way to deal with voltage and frequency regulation issues. Energy Storage (ES) devices are essential in the power system network to integrate renewable sources with the power system by converting them into a smoother and dispatch able format provide ride through capability when the distributed generation fails to supply required energy and control the amount of power required supplying during peak power demand by storing it during off-peak h. The energy storage system also provides other advantages such as prompt start up, modularity (easy plug-in), no site restrictions, limited environmental impacts and flexibility when used for power system application. These advantages depend on the type of the storage system under consideration. For this reason it is important to compare all the storage systems in general against the requirements of the power system. Major research is being done in this area but every ESS has some limitation which makes it suitable for particular application only.

RESULTS AND DISCUSSION

Appropriate control will be developed for the inerter feeding the rotor of DFIG and suitable methods for detecting the grid isolation. Simulation studies have been carried out for a wind farm equipped with 15 DFIG wind turbines to verify the effectiveness of the proposed CPC scheme. Results have shown that the proposed CPC scheme enabled the wind farm to effectively participate in unit commitment and active power and frequency regulations of the grid (Fig. 5 and 6).

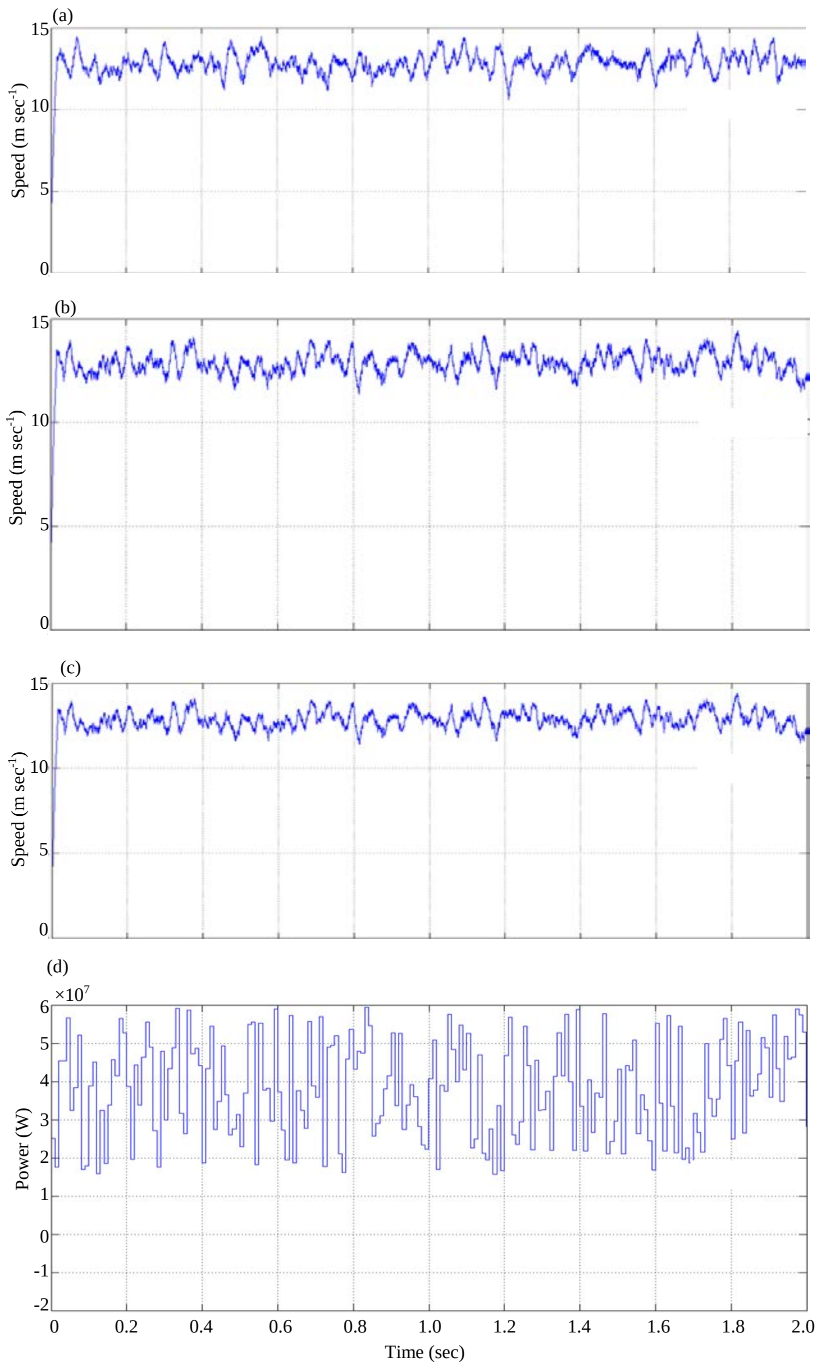

Fig. 5(a-d): The simulations results in above are wind speed (m sec^{-1}), DFIGs output characteristics

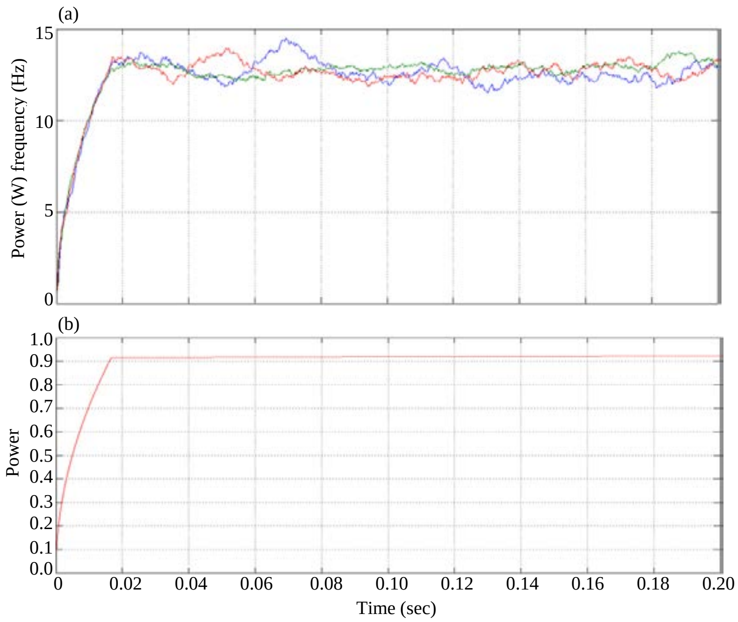

Fig. 6(a, b): Reactive power sharing p.u

CONCLUSION

The proposed system and control scheme provides a solution to help achieve high levels of penetration of wind power into electric power grids. The system is simulated in MATLAB Simulink.

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