Converter based Frequency Adjustment and Protection of Grid-tied Wind Farm

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***Abstract*— Frequency adjustment and protection of a wind turbine due to wind gust is a salient aspect of the grid-tied wind farm. Both of them require conserving system stability. This paper presents an investigation of the converter based frequency adjusting method and wind turbine protection. A grid-tied wind farm model using the Doubly Fed Induction Generator in MATLAB is used. To regulate the active power output, synchronization between wind speed and wind turbine speed is adjusted. Thus, wind farm operated at grid frequency and maximize turbine output. The control strategy of the converter based frequency synchronization of a grid-tied wind farm also includes protection subsystem. The protection system executed by receiving information from the logical block implemented in the wind farm model. It provides wind turbine protection by terminating wind turbine from a grid in abnormal wind conditions. Simulation result validates the analysis and control methods.**

Keywords—Grid-tied wind farm, DFIG (doubly fed induction generator), frequency regulation, wind turbine protection.

I. INTRODUCTION

A huge amount of electricity is required to meet up the growth of electricity demand due to the industrial revolution and modern civilization. The conventional power generation sources such as thermal, nuclear power, hydroelectric, geothermal are used throughout the world. Most of these power plants create harmful effects on the environment. All though we can't avoid these power plants totally, nonetheless it is possible to minimize those energy usages. Optimal generation mix from different sources is considered to be one of the key elements for economic growth of a country [1]-[3]. The worldwide energy policy concerned with the utilization of renewable energy resource [4], [5]. By combining the traditional energy and renewable resources, an optimized, low-cost and environment-friendly power systems can be planned. Among renewable, the wind energy's share sharply rises, and it's growing penetration demands for flexible supply resources and various options [7].

At the present time, wind energy harvesting technology by using wind turbine improves significantly than in the past. Yet the integration of wind power in the exciting power system creates a few technical challenges, power quality issues are prime among them. The term "power quality" means the stability of the voltage, the stability of frequency and the non-existence of various forms of electrical commotion (e.g. fluctuation or harmonic distortion) in the power grid [8], [16]. Combining wind generators with the existing power system could lead to many disturbances like voltage fluctuations, harmonics, flickers and frequency instability [9]. The interconnection of a large number of wind turbines to the grid creates huge trouble to the stability of power system [10], and the uncertainty associated with the uncontrolled wind system is disparaging to the power system operation as well as a control mechanism.

The remainder of the paper is prepared as follows: Section II presents the problem associated with grid-integrated with the wind power system. Frequency adjustment technique is explained in Section III. Section IV provides the intelligent converter control mechanism followed by a protection mechanism in Section V. The simulation results for several plausible scenarios are shown in Section VI. Finally, concluding notes are delivered in Section VII.

II. PROBLEM WITH GRID CONNECTED WIND SYSTEM

Among various renewable sources, wind energy is the speedily expanding energy source, which is regarded as the promotable future of renewable energy [16]. By the end of 2018, the comprehensive capacity of all wind farms installed across the world reached 600 GW, according to a report of the world wind energy association. The rate of extension in the installation of wind-power generation capacity has increased fairly, steadily over the years. So addressing the problem associated with the wind generation system is the real challenge for modeling of a grid-tied wind farm.

When the wind turbine assists a large proportion of the grid load, an irregular change in wind speed can cause voltage inequality, frequency fluctuation and flicker effects on the healthy operation. When a squall of wind hits a wind turbine blade, the blades struggle to speed up because the synchronous generator is locked to the speed of the power grid. In this situation, a huge amount of forces is developed in the gearbox, hub and generator to synchronous turbine shaft with power grid frequency. But it causes damage to the whole coupling mechanism. On the other hand, uncontrolled wind speed causes frequency fluctuation and damage of the structure for a grid-tied wind turbine system. This causes instability in the power system.

III. FREQUENCY ADJUSTMENT TECHNIQUES FOR WIND ENERGY CONVERSION SYSTEM

A grid linked wind farm system always tries to keep the system frequency close to 60/50 Hz. When generation and demand unbalance because of variable wind speed, the

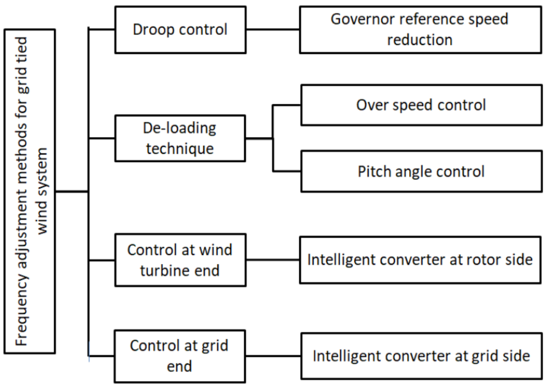

Fig. 1 Frequency tuning methods for a grid-integrated wind power.

system operating frequency starts to decrease based on system inertia and unbalanced power, according to the swing equation of power system stability given in (1) [13].

$$\frac{df}{dt} = \frac{f_0}{2H_{sys}S_G}(P_m - P_e) \quad (1)$$

Where, $\frac{df}{dt}$ denotes the rate of frequency change, f_0 is the system frequency, H_{sys} stands for the overall system inertia parameter, S_G indicates the rated power of the machine. The terms P_m and P_e are refers respectively to the mechanical power and electrical power [13]. [14].

In order to minimize the negative impact of wind power penetration on system frequency, various inertia and frequency control techniques imply for wind energy conversion system [15], [16]. Fig. 1 elaborates the techniques which apply to adjust the frequency of a grid tied wind power system.

IV. Intelligent Converter for Frequency Adjustment

With the speed change of wind, if the turbine, which converting wind power into electricity allowed to speed up immediately, the stress can be lower on the turbine. Themechanical power from wind gust can be transformed to usable electricity. Most of the wind turbine intended to operate at its standard speed to maintain synchronization of frequency between wind farms and the grid [20]. The frequency of a system linearly increases with the decrease of active power and vivaversa. Any deviation between grid frequency and wind turbine frequency can minimize by active power control of both sides.

A doubly fed induction generator (DFIG) with insulated gate bipolar transistors (IGBTs) based four-quadrant ac-to-ac converter is the best solution for a grid-tied wind turbine system. Fig. 2 presents a model of grid-tied wind farm.Doubly fed electrical generators operate similarly like an AC electrical generator, but the added feature of a DFIG is it can run at speeds to some extentoverhead or lower than its synchronous speed. The converter at rotor side and grid side of a doubly fed induction generator (DFIG) based wind turbine basically regulate the active power which eventually adjusts frequency variation of a grid-tied wind farm [21] – [24]. The four-quadrant converter in the rotor circuit of a DFIG enables decoupled control of active and reactive power of the generator.Fig. 3 illustrates the view of the converter

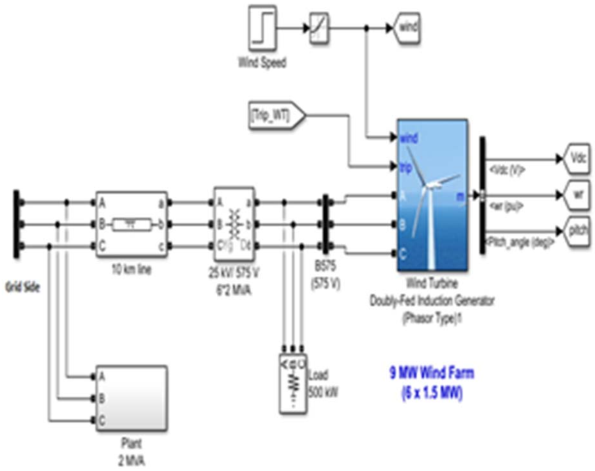

Fig. 2 Grid connected wind farm Simulink model.

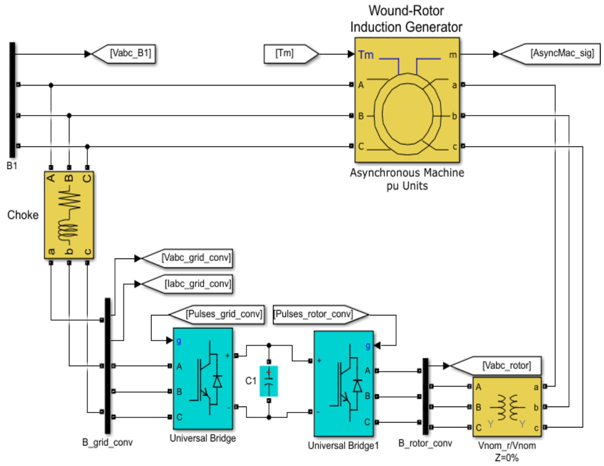

Fig. 3 Doubly Fed Induction generator (DFIG).

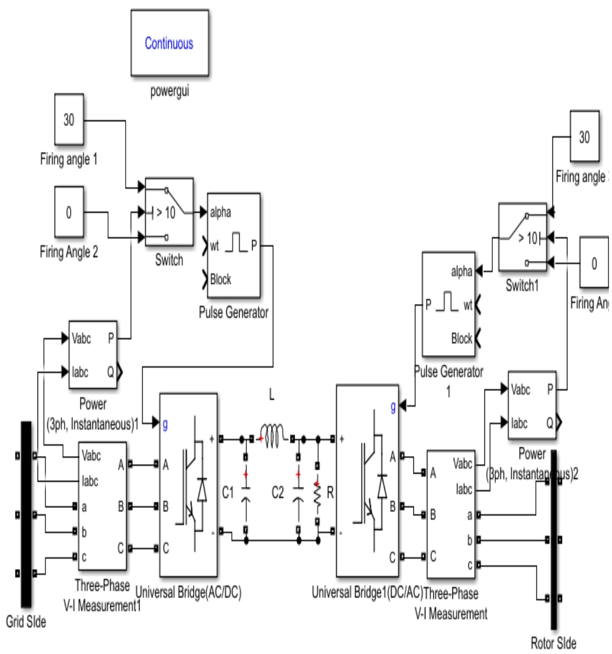

Fig. 4 Back to Back converter (AC/DC/AC) circuit

controlled Doubly Fed Induction Generator (DFIG) [25].The converter associated with DFIG is divided into two components: the grid-side converter (C_{grid}) and the rotor-side converter (C_{rotor}). Fig. 4 shows a converter circuit for controlling both the grid side and rotor side active power.

C_{grid} and C_{rotor} are force commutated Voltage-Sourced Converters that employ power electronic devices (Power MOSFET, IGBTs) to synthesize an AC voltage from a DC voltage [26], [27]. The DC side capacitor acts as the DC voltage source. The coupling inductor, L employs to connect $C_{grid}$to the grid. The brush helps to connect the three phase stator winding to the grid directly and slip ring applies to associate $C_{rotor}$with rotor winding [28].

The induction generator converts the power captured by the wind turbine into electrical power and transmitted to the grid.In Doubly fedInduction generators instead of the field winding is fed by a DC voltage and a stator winding where generates electricity; there are two individual three-phase windings, one stationary and one rotating [29]. One winding is directly connected to the grid and generates 3-phase AC power at the synchronous grid frequency. The other winding generally is known as field winding or rotor winding is connected to 3-phase AC power via a converter to create variable frequency [30]. This input power is adjusted in frequency and phase to compensate for changes in the speed of the turbine. The converter of the rotor side creates the desired magnetic field by controlling its current. The rate of rotation of the output magnetic field is the sum or difference of the rotor rate of rotation and the electric rate of rotation. If the desired frequency 50 Hz, but the shaft of the wind turbine is rotating at 49 Hz, the converter can drive the winding on the rotor with 1 Hz and the output frequency of the generated electricity will be 50 Hz.

In this way, the output frequency will always be in sync whatever the wind turbine speed is. By controlling the rotor currents precisely, the induction machine output power can be controlled. The frequency synchronizes efficiently with the grid frequency while the speed of wind varies [19]. The relationship between stator power and voltage with rotor current shows in (2), (3), (4) and (5) given by [20].

$$P_g = P_s + P_r = -\frac{V_s E_{eq}}{X_{eq}} \sin(\Theta - \delta) \qquad (2)$$

$$Q_g = Q_s = -\frac{V_s E_{eq}}{X_{eq}} \cos(\Theta - \delta) - \frac{V_s^2}{X_{eq}} \qquad (3)$$

$$V_s = j\omega_s L_s I_s + V_b \qquad (4)$$

$$V_b = j\omega_s L_m I_R' \qquad (5)$$

Where

P_s = Stator active Power

P_r = Rotor active power

P_g = Active power of grid

Q_g = Reactive power of grid

Q_s = Stator reactive power

δ = Blade Pitch Angle

V_s = The voltage of the stator

V_b = The back-EMF voltage induced in the stator by rotor current, I_R.

X_{eq}, E_{eq}= Impedance and voltage of DFIG equivalent circuit respectively

L_s,X_s&L_m=stator Inductance and Mutual Inductance

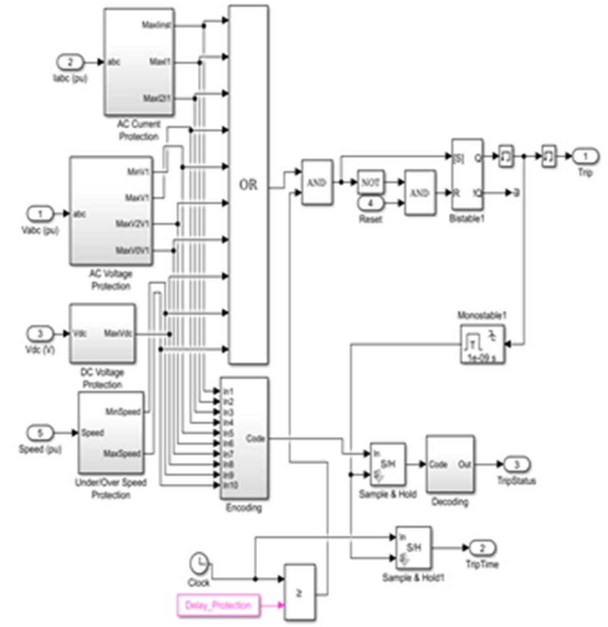

Fig. 5 Logical unit for wind turbine protection.

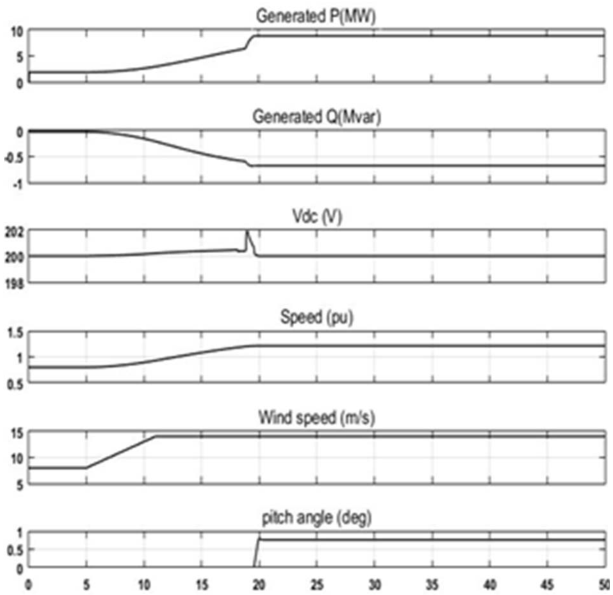

Fig. 6 Turbine response curve for maximum predefined wind speed 15 m/s.

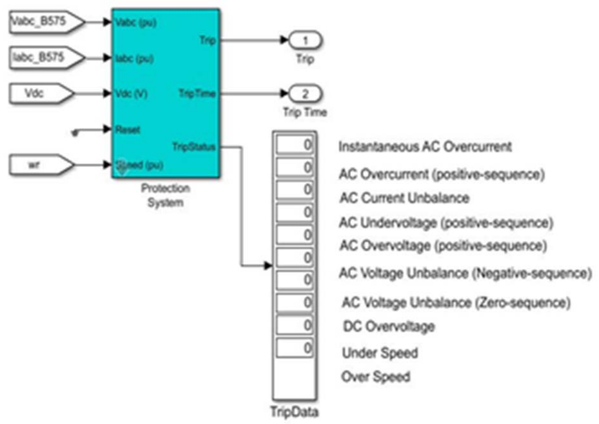

Fig. 7 Wind turbine protection module data (trip status) for maximum predefined wind speed 15 m/s.

The control system induces the voltage control command signals V_{gc} and V_r for C_{grid} and C_{rotor}respectively. By changing the firing angle of power electronics switch, the universal converter can control the power generated from the wind turbine, the reactive power, the DC bus voltage or the voltage at the grid point.

A. Rotor side converter

The rotor-side converter presented in Fig. 4 controls the voltage (or reactive power) and the wind turbine output power. The output power is controlled on the basis of a tracking characteristic which provides a pre-defined power-speed information and maintains the rated output frequency.

B. Grid side control system

The converter of the grid side shown in Fig. 4 regulates the DC bus capacitor voltage. In conclusion, the wind farm empowered a grid converter to produce or dissolve reactive power to adjust the frequency.

V. WIND TURBINE PROTECTION

A trip input is used to provide protection for the wind turbine in an abnormal condition. Fig. 5 indicates a logical unit for wind turbine protection. The block reaches a conclusion about disconnecting wind turbine from the grid on the basis of specific inputs at unexpected conditions.

When any specific input level crosses its reference level, the logical output will be high, both the grid and rotor side are decoupled the wind generator.

VI. SIMULATION RESULT ANALYSIS

The steady state and dynamic performance of a wind farm using The Doubly Fed Induction Generator in MATLAB Simulink R2017a is analysed. The wind farm consists of six 1.5 MW wind turbines. The farm transmits power to a 120 kV grid through a 30 km long 25 kV feeder under 25 kV distribution systems. A 2300V, 2 MVA plant consisting of a motor load (1.68 MW induction motor at 0.93 PF and 500 kW load) is also connected on the 575 V bus of the wind farm.

A. Wind turbine response to a change in wind speed

Initially, wind speed has kept hold at 8 m/s, and then at t=5 Sec., wind speed accelerates to 14 m/s. Waveforms for a squall of Wind (which is in Voltage Regulation Mode) is illustrated in fig 6 where a frequency adjusting converter associate for a grid-connected wind farm. At t=5 Sec., the active power generated from the wind farm elevates smoothly (together with the turbine speed) to reach its rated value of 9 MW in approximately 15 Sec. Over that time period the turbine speed raises from 0.8 pu to 1.21 pu.

At the beginning, the pitch angle of the turbine blades is set to zero degrees. If the wind speed reaches beyond its rated maximum value, the pitch angle is changed from 0 deg to 0.76 deg to limit the mechanical power. Fig. 6 conveys that the pitch angle remains in its initial value zero up to maximum wind speed.

If the wind speed reaches beyond is a predefined maximum value, pitch angle increase with the increase of wind speed to divert the turbine blade out of the wind gust with turbine speed to adjust the system frequency to its

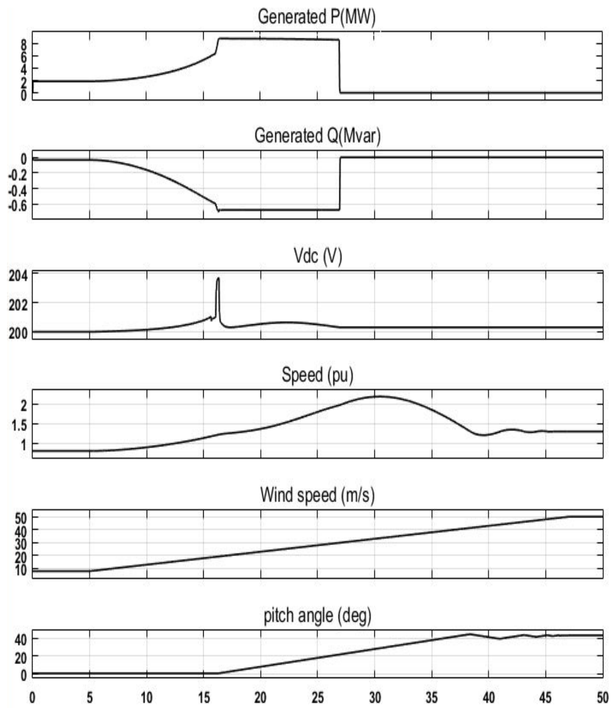

Fig. 8 Turbine response curve for wind speed 50 m/s.

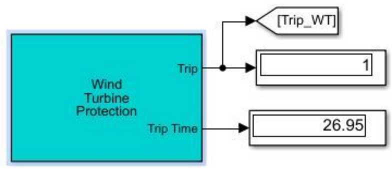

Fig. 9 Wind turbine protection module data (trip time) for over speed wind.

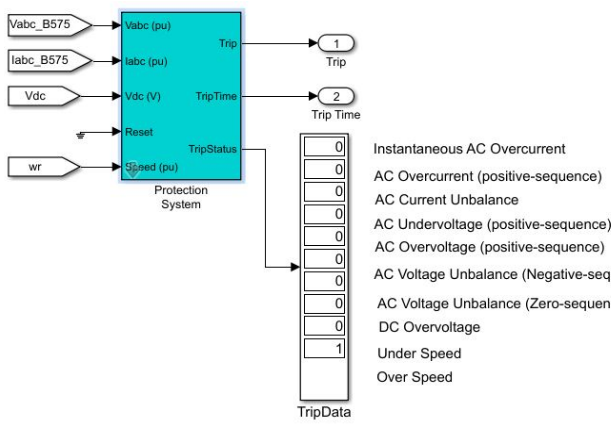

Fig. 10 Wind turbine protection module data (trip input) for over speed wind.

constant value.All the trip status is zero shown in the trip module (Fig. 7) as the wind turbine is operating in between its maximum level.

Fig. 8 implies that the pitch angle of the turbine changes rapidly with the change of wind speed. This is done so to keep the rotor blades at the desirable angle to maximize output in all wind speeds. Blades are angled to protect the wind turbine from wind gust or over speed wind. Fig. 8 also implies the fact that the power generated from wind turbines is zero when wind speed is over than predefined maximum speed. At that moment trip circuit activated and disconnects the wind farm from the connecting grid.

Fig. 9 and Fig. 10 shows when wind speed (50 m/s) is over than predefined maximum speed (15 m/s), the trip input is high in the wind turbine protection module. The wind turbine trips at 26.95 Sec when the wind speed reached over than maximum speed.

VII. CONCLUSION

In concern to the energy demands and environmental prospect, wind energy is considered as one of the best and clean solutions. But the integration of wind energy in the exciting grid introduces few factors of uncertainty. Interaction of feedback control, intelligent power electronic based controller could improvise frequency adjustment mechanism as well as system instability by ensuring system protection. The analytical study of this paper emphasizes on the fact that a well-designed interfacing of power electronics based converter with grid-tied wind farm can effectively and efficiently synchronize frequency between the power system grid and wind farm by controlling active power and the pitch angle. Also a smart logic control block can protect the coupling structure of grid-tied wind farm in unanticipated wind speed condition. The limitation of this paper is that the other feature of the trip module is not included in the discussion.

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