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Effect of Wind Turbine Distributed Generation on the Power System Stability

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Abstract: - In order to keep up with the annual growth in demand for electric energy, distributed generation (DG) is becoming more and more prevalent. Connecting distributed generation (DG) to an established distribution system offers multiple advantages to stakeholders, including the utility, customers, and owner. DG can peak shave and fill troughs and deliver improved power quality and distribution system reliability. Nonetheless, there are a number of technological, financial, and legal considerations related to incorporating DG into current networks. One of the main problems with a DG's penetration into an existing distribution system is the instability and protection of the power supply. In addition to raising the system's fault level due to the DG's connections, DG causes the system to lose its radial power flow. When a distribution system's condition changes, so does it short-circuit power. When certain generators within the distribution system are removed, there is also a shift in short-circuit power. As a result, new protection strategies for utility distribution networks as well as DG have been created recently, however, the problem has not been adequately resolved. This study examines how distributed generation (DG) affects the stability of an electrical power system in a wind turbine distribution system. The effects of distributed generation (DG) on the stability of the low-voltage power system are examined by comparing the obtained results with those of the typical situation.

***Keywords**:* Distributed generation, Power system, Stability, Wind turbine

1. Introduction

Traditionally, electric power is produced at central station power plants and delivered to consumers using transmission and distribution networks. There is currently a movement toward the usage of distributed generation (DG) units in addition to the conventional huge generators connected to the transmission system for reasons related to economy, technology, and the environment [1]. Therefore, it is anticipated that in the near future, DGs will play a major role in electrical power networks. Distribution networks are the primary means of connection for DG units. As a result, the technical features of the distribution networks are impacted by the installation of these units [2-3]. In general, a small number of distributed generation units (DG) can be disregarded because, in contrast to big centralized power plants, they will not have an impact on the transmission system's functionality. Because of this, they are typically regarded as negative loads in power system stability studies, and neither their intrinsic dynamics nor their controllers, if any, are taken into consideration [4]. Certain renewable technologies, like solar panels and wind turbines, rely on the availability of renewable resources, hence their output power is not always constant. In these situations, energy storage devices are employed to supplement the DGs during low power times [5]. In addition to solar and wind power, storage can help balance the power when used with biomass, particularly in rural areas where combined heating and electricity is used. When demand is low or power is high, these devices store energy, which is then used to power surplus loads when power is low [6]. Apart from aiding the distributed generators (DGs) during periods of high demand, the storage devices could potentially enhance the overall stability of the entire system. Appropriate power conversion devices are used to link these energy storage devices to the electrical grid. While meeting local electricity demand is the primary goal of distributed generation (DGs), DGs can also be connected to the electric grid to supply excess power when energy production surpasses local need [7]. Depending on a number of variables, including system size, type, and loads, distributed generation can have a positive or negative impact on the distribution system and grid as a whole. To evaluate the impact, dynamic modelling and simulation are required [8-9].

Numerous studies in the field of reliability assessment in distribution networks with DGs have been conducted. Previous research has examined the arrangement of distributed resources, with a focus on improving voltage profile, lowering power loss, and boosting system reliability [10]. In other works, reliability evaluation has been conducted when distribution networks are considered as a market place [10-11]. Since DGs might be installed in different feeder sections, it is necessary to develop an analytical method for assessing the dependability of a feeder that has DG installed in many feeder sections. DG refers to the integration of renewable energy sources at the distribution level. Because intermittent renewable energy sources are becoming more and more prevalent in distribution systems, the utility is concerned about potential threats to network stability, voltage regulation, and power-quality (PQ) issues [12]. Thus, in order to guarantee the safe, dependable, and effective operation of the entire network, the DG systems must adhere to stringent technical and legal frameworks. The development of digital control and power electronics has made it possible to actively operate DG systems, improving PQ, stability and system performance.

2. Objectives

In this paper, the impacts of synchronous generator interfaced DGs on power system transient stability are investigated more based on simulation technique. The main aim of this study is to investigate the impact of different configuration and penetration levels of any DG and their stability for low voltage electrical power systems. It is also tried to develop solutions for issues with stability in presence of a significant number of DG.

3. Methods

One of the innovative ideas in power systems being employed to meet the rising energy demand is distributed generation, or DG. DG can be divided into two main categories: rotating machine DG and inverter-based DG. Inverters are typically employed in distributed generation (DG) systems after the generating process since the generated voltage, which can be either DC or AC, must be adjusted to the nominal voltage and frequency. As a result, it needs to be rectified to convert it from AC to DC and back to AC with the nominal characteristics. The electrical power system is made up of multiple parts.

3.1. Photovoltaic Systems

An electric energy source is created from solar light using a photovoltaic system. In this system, photons, which are self-contained energy, are converted into electricity using solar cells made of semi-conductive materials when exposed to sunlight. To produce the most power, the cells are arranged in a moving or fixed array that continuously tracks the sun. These systems are simple to use, emit no emissions, and just require solar light as fuel. They are also environmentally benign. However, they are expensive initially and require huge locations. A schematic diagram of a photovoltaic system is shown in Figure 1.

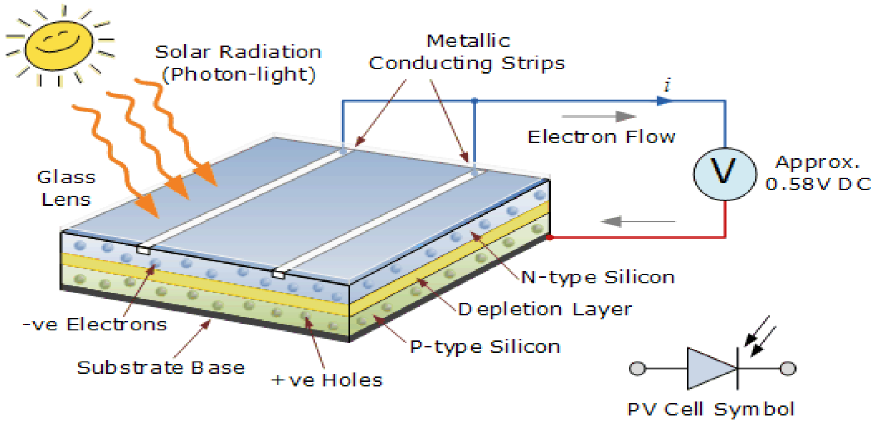

Figure 1: Schematic diagram of a photovoltaic system

3.2. Wind turbine

Wind energy is converted into electricity by wind turbines. Since the wind is an extremely volatile source that cannot be stored, it needs to be treated as such. There are two conversion phases in a wind turbine's operating principle. The rotor first captures wind energy and transforms it into mechanical torque in the shaft. Next, the generation system uses this torque to produce electricity. The generator system in the most popular setup produces an AC output voltage that is based on wind speed. Because wind speed varies, inverters are required to convert the generated voltage from AC to DC and back again. On the other hand, fixed-speed wind turbines are connected directly to the grid.

3.3. Fuel-Cell

Fuel cells operation is similar to a battery that is continuously charged with a fuel gas with high hydrogen content; this is the charge of the fuel cell together with air, which supplies the required oxygen for the chemical reaction. The fuel cell utilizes the reaction of hydrogen and oxygen with the aid of an ion conducting electrolyte to produce an induced DC voltage. The DC voltage is converted into AC voltage using inverters and then is delivered to the grid. A schematic diagram of fuel-cell is shown in Figure 2.

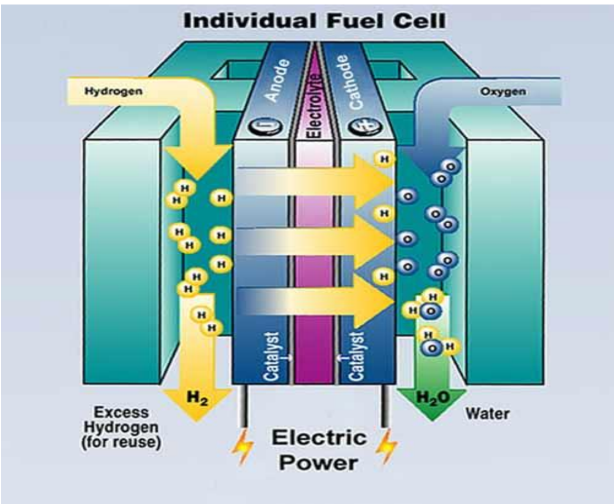

Figure 2: Schematic diagram of fuel-cell

3.4. Impact of distributed generation on power system grids

The power flow and voltage conditions at utility equipment and consumers can be greatly affected by the addition of distributed generation (DG) to systems that were initially intended to function without any generation on the distribution system. Depending on the distribution system operation characteristics and the qualities of the distributed generation, these affects may have a favourable or negative effect. Radial distribution systems, for instance, use shunt capacitors on feeders or along the line, line regulators on distribution feeders, and load tap changing transformers (LTC) at substations to help control the voltage. One-way power flow underpins voltage regulation, and regulators with line drop compensation are part of this system. The connection of DG may result in changes in voltage profile along a feeder by changing the direction and magnitude of real and reactive power flows.

Using load flow analysis software, which can investigate the optimal location for DG to be installed in the system to reduce losses, one can ascertain the best location for DG to be installed. For instance, if the feeders have substantial losses, adding multiple DGs with moderate capacities will significantly improve the losses and benefit the system. In a similar vein, DG's presence in a network influences its short circuit levels. When DG is not placed in the network, the fault currents increase as compared to standard conditions.

When chosen properly, both the types and locations of distributed generation can enhance the stability of power systems. When it comes to oscillatory stability, using DG enhances the electromechanical modes' damping and marginally raises their frequency. The time-domain simulation of a few perturbations confirms this fact. The transient stability analysis demonstrates that as the penetration level of the DG units increases, the maximum power-angle deviations between the generators decrease. Nonetheless, another disruption to the network is the disconnecting of some DG units when the voltage falls below 80% of the nominal value.

4. Analysis of network in electrical power system

The primary focus of this research is on the factors that lead to machine speed fluctuations and the development of power swings during gusts and ramps in distributed generation (DG) wind mills. It is necessary to do a performance analysis of the mechanical torque of the turbine and the electrical torque of the synchronous generator in a wind farm. The goal is to lessen the impact of windmill gusts and ramps. In order to keep the system stable, the power system stabilizer (PSS) is utilized to dampen down the rotor oscillation modes. The examination of machine power, speed, and load angle under ramp and gust conditions, with or without PSS is also included in this paper. Simulating the suggested stabilizer with PSCAD software allows for evaluation.

4.1. Wind-turbine modelling

The wind turbine model is taken from the PSCAD simulation library. Such a model requires the input variables wind speed in m/s, pitch angle in degrees, and rotor speed in PU quantity. The mechanical torque produced by the wind turbine model is also given in PU.

4.2. Synchronous machine modelling

The equivalent circuit of a synchronous generator represents the complete characteristics, including the voltage equations, as shown in the Figure 3. In these equivalent circuits, voltages as well as flux linkages of the synchronous machine model at the d axis are as follows (shown in Figure 3):

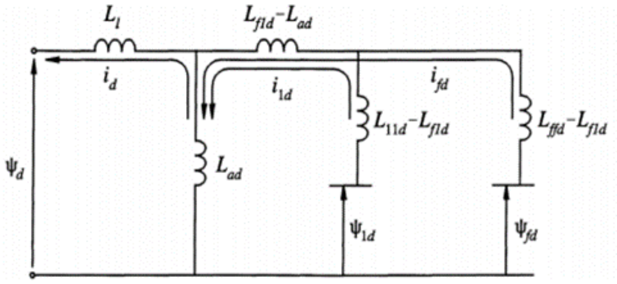

Figure 3: Schematic diagram for the equivalent circuit of synchronous machine model

$$L_{fd} = L_{ffd} - L_{f1d} \quad (1)$$
$$L_{1d} = L_{11d} - L_{f1d} \quad (2)$$
$$L_{1q} = L_{11q} - L_{aq} \quad (3)$$
$$L_{2q} = L_{22q} - L_{aq} \quad (4)$$

4.3. Modelling of the mechanical system

The model of the mechanical system uses the synchronous generator currents as an input variable and provides as outputs the rotor speed and the electromagnetic torque of the synchronous generator. The electromagnetic torque, T_e, is calculated using the following formula:

$$T_e = \left(\frac{1}{2}\right)\left(\frac{nf}{2}\right)\left[(Ld - Lq)t_d t_q + tq\lambda o\right] \quad (5)$$

If (L_d-L_q) is stated as Ld_q, then Te can be stated as:

$$T_e = (0.75)n_p i_p(L_q i_q + \lambda o) \quad (6)$$

The dynamics of the generator speed w_g can be stated as:

$$\frac{dw_g}{dt} = \frac{T_e - Tw_g - B_m wg}{J_{eq}} \quad (7)$$

Where, the w_g represents the generator parameters, J_{eq} is the moment of inertia of the WT, (where $J_{eq} = Jw + Jw/{n_g}^2$ with $n_g$is the gearbox ratio), B_m is the damping coefficient of the turbine.

4.4. Power Swing

Power swing is caused by large disturbances in the power system, which, if not blocked, could cause the wrong operation of the distance relay and generate the wrong or undesired tripping of the transmission line circuit breaker. And if not prevented, the generator could cause severe damage to the machine. When there is an imbalance between the torques acting on the rotor, the net torque causing acceleration (or deceleration) is:

$$T_a = T_m - T_e \quad (8)$$

Where,

T_a= Accelerating torque in N-M

T_m= Mechanical torque in N-M

T_e= Electromagnetic torque in N-M

The combined inertia of the generator and prime mover is accelerated by the unbalance in the applied torque. Hence, the Swing Equation is,

$$J\frac{dw_m}{dt} = T_a = T_m - T_e \quad (9)$$

Where, J = combined moment of inertia of generator and turbine, kg.m^2

4.5. Layout of synchronous generator using wind turbine to the low voltage power system grid

Layout of synchronous generator using wind turbine to the low voltage power system grid is shown in Figure 4:

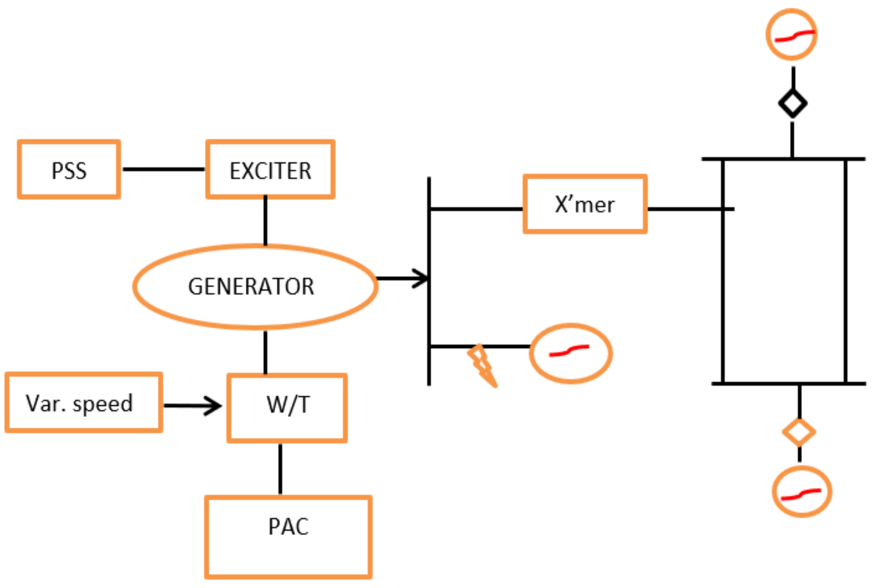

Figure 4: Schematic diagram of synchronous generator using wind turbine.

5. Results and Discussion

The analysis of effect of distributed generations of the stability of electrical power system is done based on simulation model in PSCAD. The analysis is done by considering with and without effect of ramp and gust in wind turbine with PSS. For that the input voltage and current single is shown in Figure 5 and 6, respectively.

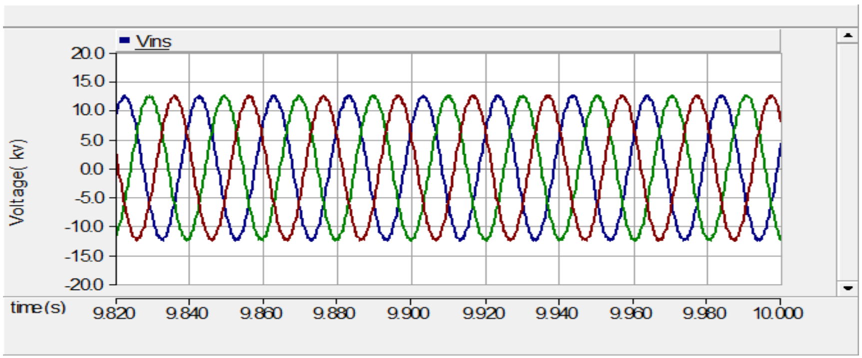

Figure 5: Input voltage signal for analysis

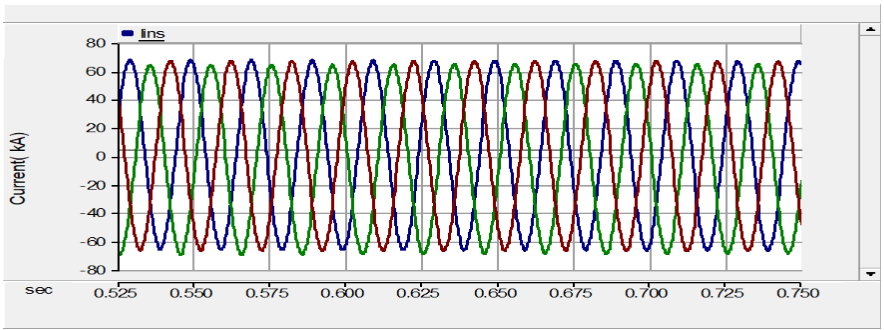

Figure 6: Input current signal for analysis

The output responses for different parameters are shown in Figure 7 for without effect of ramp and gust in WT connected with PSS.

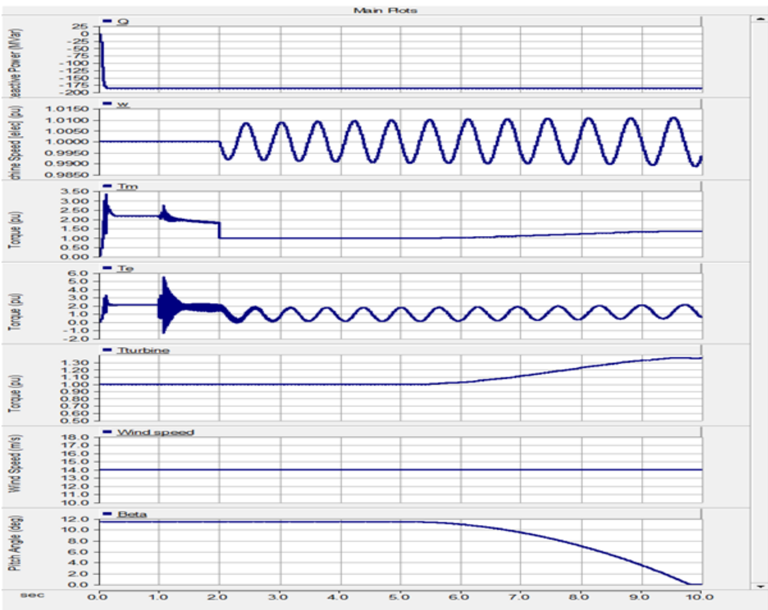

Figure 7: Output responses without effect of ramp and gust in WT connected with PSS

Similarly, simulation results without effect of ramp and gust in WT connected without PSS are shown in Figure 8.

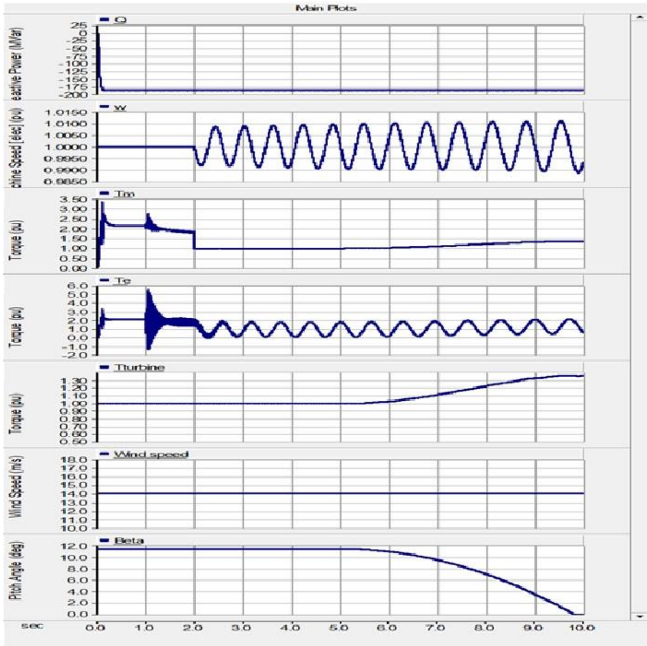

Figure 8: Output responses without effect of ramp and gust in WT connected without PSS

Similarly, simulation results considering effect of ramp and gust in WT connected with PSS are shown in Figure 9.

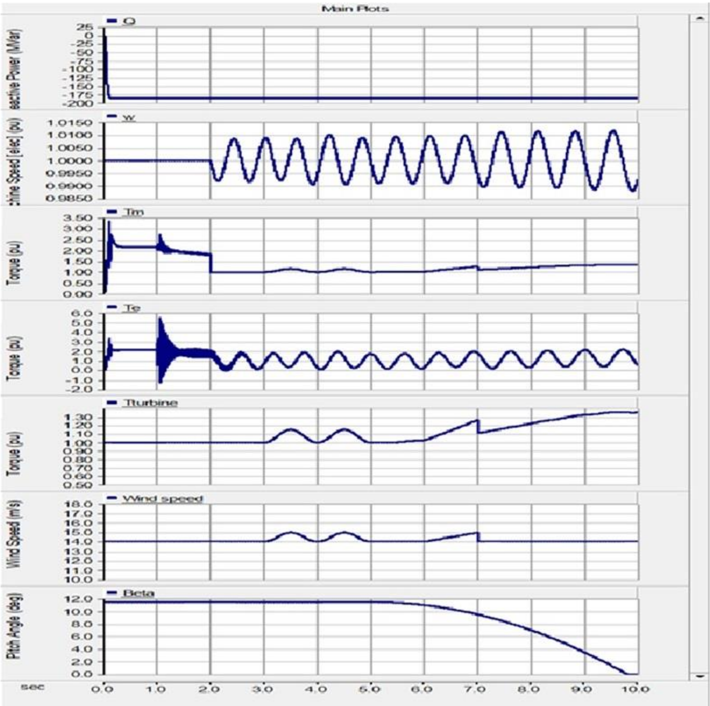

Figure 9: Output responses considering effect of ramp and gust in WT connected with PSS

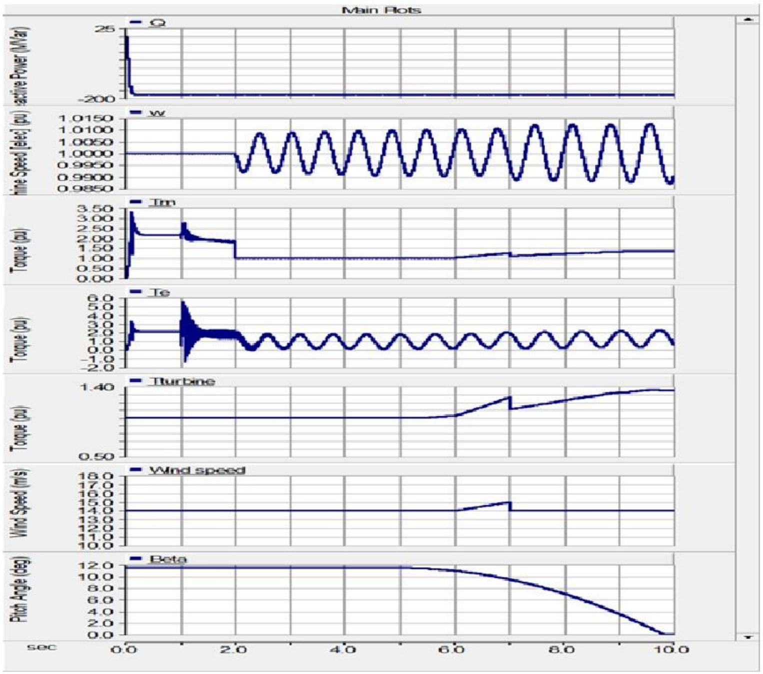

Figure 10: Output responses considering effect of ramp in WT connected with PSS

Similarly, simulation results considering effect of ramp in WT connected with PSS are shown in Figure 10. In this condition, the wind speed at ramp condition where the ramp is applied at 6.0s of velocity 3m/s for 2.0s duration. The effect of ramp is clearly observed at figure below in machine rotor speed (pu) where the power swing is gradually decreases by the use of PSS. Simulation results considering effect of gust, ramp, noise and damp in WT connected with PSS are shown in Figure 11. More harmonics are seen. The system becomes unstable. These are shown below,

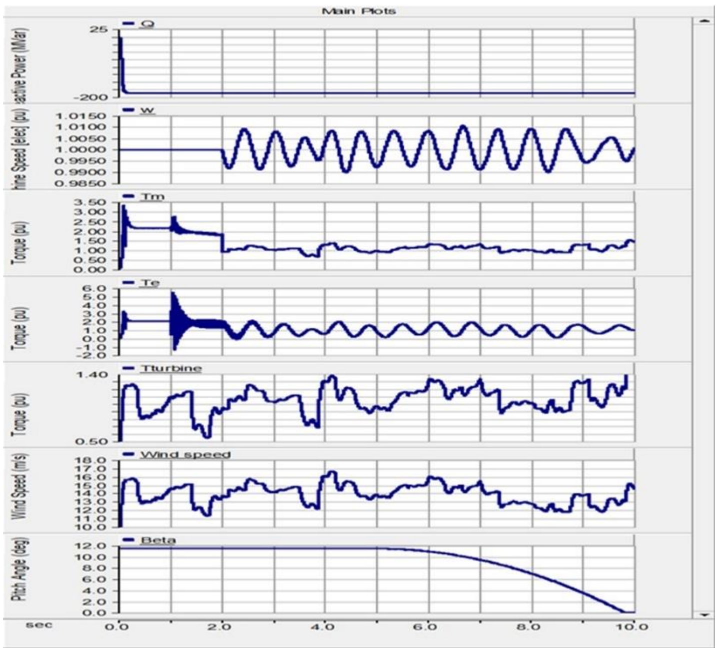

Figure 11: Simulation results considering effect of gust, ramp, noise and damp in WT connected with PSS.

6.Conclusions

The primary objective of this study is to examine the potential effects of various DG topologies and penetration levels on power systems stability. In this experiment, some DG technology typically wind turbines were used. These technologies differ from the commonly used energy generation technologies, mostly because to the unpredictable nature of the energy source (wind turbines, photovoltaics). Regarding the kind of connection to the primary utility, two basic categories may be distinguished: generators that employ power electronic converters and those that are directly connected, such as synchronous or induction generators. When problems occur, synchronous generators are the most frequent cause. Less contribution is made by induction generators, which are also quite damped. Lastly, because the output of power electronic converters is restricted to the rated current, they are unable to sustain large overcurrent. As a result, the many technologies that are connected to the power system have an impact on it. Consequently, it is necessary to analyse the potential impact of each DG technology on system protection. There are following outcomes have been found from this study:

- Any distribution system that a DG penetrates has a rise in fault level inside the network.
- A DG loses its properties of radial power flow when it penetrates the system.
- Certain branches experience a drop in SC current while the DG is present, which causes the protection devices to become less sensitive.
- The fault current value falls with increasing distance between the DG and the fault spot.
- If a fault arises upstream of the DG, loads and protective devices downstream of the DG will not be exposed to the contributed fault current of the DG.
- A reduction in the contribution results from a higher degree of DG penetration into the network.

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