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Power Flow Analysis in a Wind Turbine Based Distributed Generation for Protection of a Power System

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Abstract— *The paper deals with the active and reactive power flows in a wind turbine based Distributed generation (DG) injected power system The connection of distributed generators (DG) to distribution networks greatly influence the performance and stability of such networks. In the proposed work, separate wind turbine based generation system have been considered these energy source is coupled to an induction generator which is interfaced to the grid through a rectifier inverter pair. The objective is to inject scheduled amount of real and reactive powers in to the grid while maintaining the balance between input and output power. wind turbine based DG injects the real power in the grid depending upon the prevailing wind speed. In this case DG remains unaffected by the variation in the load demand and the surplus power is fed by the utility itself. When the DG is producing active power, the voltage at its connection point will increase which might lead to an over voltage. On the other hand, when the DG is inactive and with heavy local load, the voltage might drop, giving low voltage. Therefore we have to avoid all abnormal voltage conditions, both under voltage and also over voltage The simulations have been performed using Mat lab /Simulink.*

Index Terms— *Distributed Generation, Induction Generator , Power Flows, Reactive Power, Real Power,, Power System Protection., Wind Turbine*

1 INTRODUCTION

THE traditional approach in an electrical power system has been to have centralized large Capacity power plants feeding power to distant load centers through an extensive transmission and distribution network. Due to environmental concerns regarding pollution, accidents and loss of forested area Distributed Generators have emerged as a viable alternative to conventional power generation. DG provides electric power there by eliminating the need to upgrade transmission lines and increase the capacity of remote power plants. For conventional radial feeders, without any DG, the power flows only in one direction from the feeding grid towards the loads. Therefore the voltages decrease towards the end of the feeder. When DG is added in a system, we have to consider the situation when the DG exceed the local load and power flows in reverse direction, that is, towards the high voltage grid. Hence, the power flow can either be from the grid toward loads, or vice avers. Then we have two very different load flow situations to consider in the power system analysis. The opposite load flow conditions give totally different voltage distribution in the system. Hence, the conventional voltage control systems and protections might be In appropriate when we have DG

2.WIND TURBINE TECHNOLOGY

2.1 Wind Power

Windmills or wind energy converters convert wind power to electrical power. Typical systems range from 30 kW for individual units to 1.5 MW for wind farms of multiple units. Hub-heights are around 80 meters, and rotor diameters are 65 m. Rotor construction is either variable blade angle (pitch regulation) or non-variable, conversion from mechanical to electrical energy is via either synchronous or induction generators. Synchronous generators are usually equipped with pulse width modulated converters, control of these converters is essential for regulating the behavior of the windmill on the electric grid. Windmills are often installed in groups, or wind farms, and are seldom used in isolation. Techniques for using HVDC links to connect wind farms to

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transmission grids.

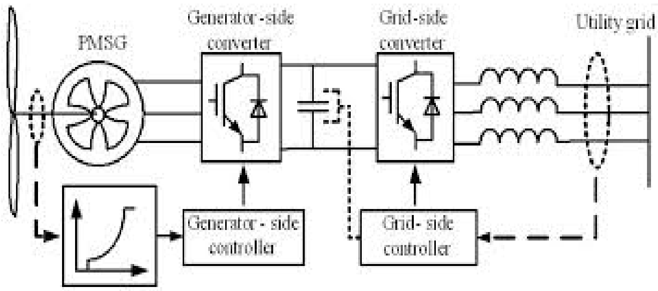

Fig 2.1 Wind turbine typical

Typical costs are around 1000 $ / kW, and electrical efficiencies around 25%. However, it must be noted that efficiency should not be compared with fuel cell or micro-turbine efficiency due to the renewable fuel source.

2.2 History and status

Wind mills have been used for many years to harness wind energy for mechanical work such as pumping water. Before the rural electrification Act in the 1920's provided funds to extend electric power to outlying areas, frames were using windmills to produce electricity with electric generators. In the US alone, eight million mechanical windmills have been installed.

Wind energy becomes a significant topic in the 1970's during the energy crisis in the U.S and the resulting search for potential renewable energy sources. Wind turbines, basically windmills dedicated to producing electricity, were considered The most economically viable choice within the renewable energy portfolio. During this time, subsidies in the form of tax credits and favorable federal regulations were available for wind turbine projects to encourage the penetration of wind turbines and other renewable energy sources. Today, attention has remained focused on this technology as an environmentally sound and convenient alternative.

2.3 Operation

Wind turbines are packaged systems that include the rotor, generator, turbine blades, and drive or coupling device. As the wind blows through the blades, the air exerts aerodynamic forces that cause the blades to turn the rotor. Most systems have a gearbox and generator in a single unit behind the turbine blades. The output of the generator is processed by an inverter that changes the electricity from DC to AC so that the electricity can be used. Fig 3.4.2 shows the typical wind turbine system.

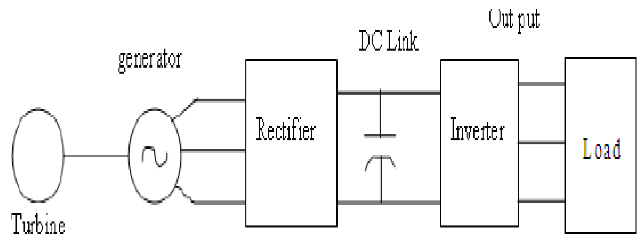

Fig. 2.2. Wind turbine based power system

Most of the turbines in service today have a horizontal axis configuration (as shown in the figure). Wind conditions limit the amount of electricity that wind turbines are able to generate, and the minimum wind speed required for electricity generation determines the turbine rating. Generally, the minimum wind speed threshold is attained more frequently when the turbine is placed higher off of the ground. Also important to consider when sitting a wind turbine is the terrain. Coastlines and hills are among the best places to locate a wind turbine, as these areas typically have more wind.

3 MODELLING OF WIND TURBINE

3.1 Wind turbine model

The wind turbine is characterized by non-dimensional curves of the power coefficient Co, as a function of both tip speed ratio e, and the blade pitch angle, e. The tip speed ratio e is the ratio of linear speed at the tip of blades to the speed of the wind. It can be expressed as follows

$$\lambda = \frac{\Omega R}{V_w} \quad \text{……………………. (3.1)}$$

Where **R** is the wind-turbine rotor radius, Ω mechanical angular velocity of the Wind-turbine rotor and $_V$, is the wind velocity. For the wind turbine used in the study, the following form approximates Co as a function of e **and e**

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$$C_p = (0.44 - 0.0167\beta)\sin\left[\frac{\pi(\lambda - 3)}{15 - 0.3\beta}\right] - 0.00184(\lambda - 3)\beta$$

……… (3.2)

The output mechanical torque of the wind turbine, *T,* can be calculated from the following equation

$$T_m = \frac{1}{2}\rho A R C_p V_w^2 / \lambda$$

………(3.3)

Where is the air density and A is the swept area by the blades.

3.2 Characteristics of Wind-turbine

A typical wind-turbine torque-speed characteristics is given in fig. the torque developed by the wind-turbine is dependent on the wind speed and the angular rotor speed of the wind-turbine. Here, the relation between the wind-turbine out put torque and the rotor speed at different values of wind speed is depicted. It is clearly seen that with the increase in the wind speed the out put torque increases. For each curve, the region to the left of it's peak is considered to be the stable region of operation.

For a typical wind-turbine, the C_p-λ characteristics, for different values of the pitch angle β, are illustrated in fig. the maximum values of power coefficient, C_p (C_{pmax}=0.48) is achived for β of o degree and for λ of 8.1. this particular value of λ is defined as the nominal value (λ_{nom}).from this characterstic, it is seen that with the increase in the value of pitch angle β, the value of power coefficient C_p decreases. In the present simulation e is kept constant at zero value.

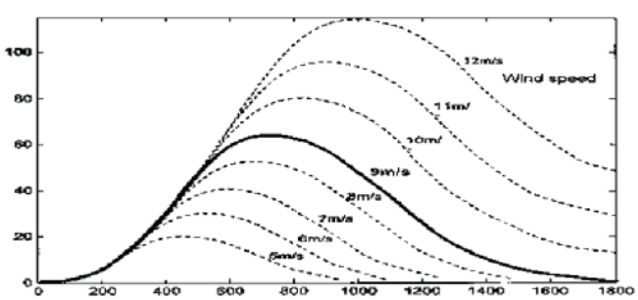


Fig 3.1.1. Wind turbine out put torque as a function of rotor speed

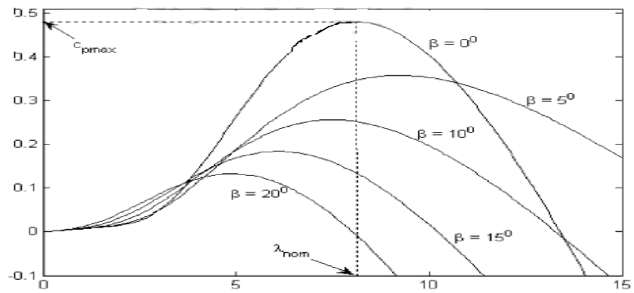


Fig 3.1.2. C_p-λ Characteristics for a typical wind turbine

Wind-turbine rotates at almost constant speed. In case of high wind speeds, the pitch angle β can be varied in order to minimize the effect of wind gust.

On a pitch- controlled wind-turbine, the turbine's electronic controller checks the power output of the turbine several times per second. When the power output becomes too high, it sends an order to the blade pitch mechanism, which immediately pitches(turn) the rotor blades slightly out of the wind. Convesly, the blades are turned back in the wind whenever the wind drops again. The rotor blades thus have to able to turn around their longitudinal axis (to pitch). During normal operation, the blades will pitch a fraction of a degree at a time and the rotor will be turning at the same time. On a pitch-controlled wind- turbine, the computer will generally pitch the blades a few degrees every time the wind changes in order to keep the rotor blades at the optimum angle in order to maximize output for all wind speeds. The pitch mechanism is usually operated using hydraulics. For high- speed winds, a dumping resistance can be added to absorb the extra power supplied by the wind turbine.

4. POWER FLOW ANALYSIS

The most readily apparent limitation when integrating new DG to a distribution system is likely to be one of *overflow* (current capacity limits). For the most part, installing DG to a system should reduce power flow within transmission and distribution lines as it supplies power to local loads and reduces the amount of power required from a distant power plant, and thereby reduces line losses. However, it is also possible that a DG could *increase* the power flow of a particular line. For this case, current capacity limitations must be addressed. If existent grid equipment is already seeing power flow nearing its duty ratings, a nearby DG unit might cause an overload. Similarly, the DG will increase many fault currents which may exceed levels acceptable for existent relays, and nuisance tripping may occur even under normal operating conditions; these issues will be discussed at length in the section on protection scheme disturbances.

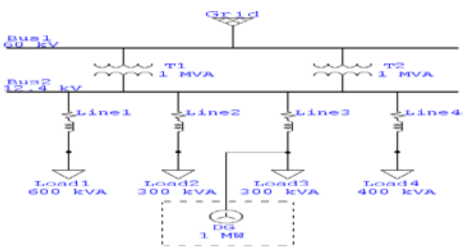


Fig 4.1 Distribution System

To illustrate the issue of overflow, consider the system of Figure 4.1 in which a substation feeds a distribution system composed of four radial feeders; the possibly various loads on each feeder are modeled here a one lumped at the end of the feeder (with a 90% power factor each). Without the presence of DG anywhere on the system, Line 3 will have 14A/phase flowing through it to service Load 3. Therefore, the line may be rated at 25A/phase so the line can service the load up to 150% loading without damage.

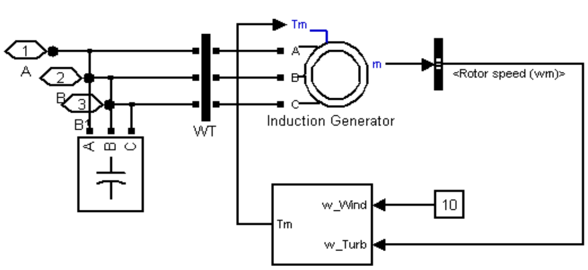
However, if a DG unit were to be connected to the system, such as the one shown on Line 3, power flows would be altered. The DG shown here produces 1MW at a 90% power factor, which could be a single generator or could be the model for a combined capacity of multiple units connected along Line 3 at different points. This DG unit would provide 70% of real power demand for the distribution system, alleviating demand from the grid. However, the power fed to the loads on the other lines would amount to more than 31A flowing through Line 3 to Bus 2, causing an overload of the line. The system could not handle this DG installation as illustrated unless Line 3 were upgraded or another line were added between the DG and Bus2. Also to be noted from the system illustrated, is that power flow is found flowing directly from the substation bus to the loads without DG presence. Yet with DG installed, the additional power that could cause an overflow would be flowing in the opposite direction – from the DG unit to the substation bus. Even if a smaller sized DG unit were installed so that no overflow occurred, there could still be power flow in the direction from the load to the substation bus.

Typical distribution systems primarily involve only unidirectional power flow at the distribution level and control techniques are employed accordingly. Power is generally assumed to flow from *upstream* (power plants; HV lines) to *downstream* (consumers; LV lines). When DG is added to a distribution line, it can cause *power flow reversal*, meaning that power may then begin to flow upstream within a section of the system that has been engineered specifically for downstream flow. Therefore, a power flow study along with loading and generation profiles may be necessary, prior to the installation of new DG, to ensure that there is no reversal of power flow or, at least, that any potential reversal will not disturb grid operation. Even if nominal operation does not cause problematic power flow reversal, extreme cases must be accounted for. The 21 system may need to be able to handle a case when the DG has maximum output and local loads are at their minimum. The degree of concern with this issue, of course, is very dependent on the specific DG design being employed. Solar generation is often minimal at night when loads are also minimal, which inherent reduces the possibility of generation exceeding load demand during light loading conditions. Some DG operators may opt to employee dynamic control system to monitor the system and adjust output levels accordingly. The issue of power flow reversal will be unique in each DG case; the issue must be addressed with regard to the specific generation unit being implemented as well as to the specifics of the distribution system it will interconnect with.a practical design technique for evaluating a potential DG site then, is to begin first by identifying all duty ratings and current capacity limits of the grid equipment that will be affected. These limitations will either reveal the limitation on maximum power output of the DG unit, or reveal the equipment that needs to be upgraded to accommodate the DG, or both. Difficulty may lie in deciding just how far upstream and downstream one must investigate; a basic load flow analysis should give insight into which areas are pertinent, but contingency cases and other abnormal operating conditions may cause the DG presence to affect areas further than anticipated. With common radially fed distribution systems, the feeder lines often have a single point of source supply coming from a substation transformer or bus. System design may become complicated if there is the possibility of a power flow reversal that would cause an upstream flow to this source. Therefore, a practical design (technically and economically) would require that the DG output power be limited to a quantity that does not cause an upstream flow (at least on the average) – that is, the DG unit supply should not exceed the local demand load. Feeding power upstream from a radial distribution line o its supply source can cause issues not easily mitigated.

5. Simulation Analysis of wind turbine

Wind turbine based DG injects the real power in to the grid depending upon the prevailing wind speed. In this case DG remains unaffected by the variation in the load demand and the surplus power is fed by the utility itself. the modeling of wind turbine is designed by considering the following parameters.

Hub heights = 80 m
Rotor diameter = 65m/s
Wind speed = 15m/s
Turbine speed = 1800 rpm
Blade pitch angle = 0 -20^0
Power coefficient = 0.48
Inertia constant = 2
Friction factor = 0



5.1.1 Wind Turbine

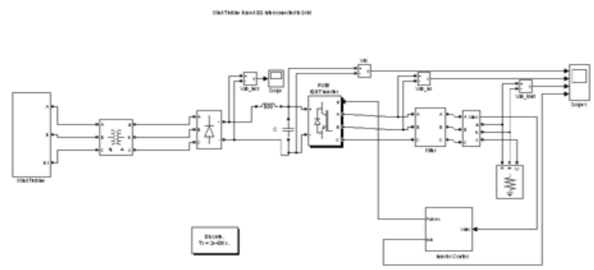


Fig 5.1.2 Wind Turbine connected to grid

5.2 WIND TURBINE RESULTS

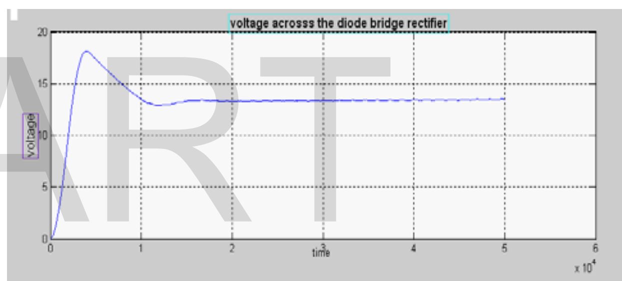


Fig 5.2.1. Voltage across the diode bridge rectifier

The voltage at the output of bridge rectifier is shown in the figure5.2.1 .the voltage waveform takes 1.1s to reach the steady state as shown

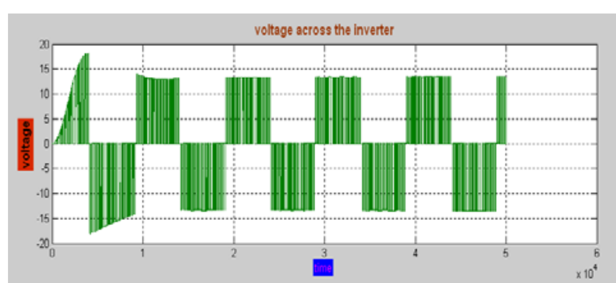


Fig5.2.2. Voltage across the inverter

The DC voltage at the diode bridge rectifier is converted back in to AC using the two level three phase voltage source PWM inverter which is shown in the above figure 5.2.2

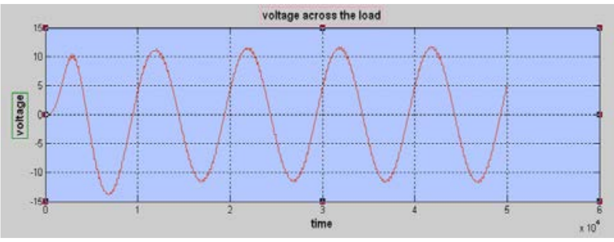


Fig5.2.3. Voltage across the load

The line voltage and RMS pew voltage are shown in the above figures5.2.3 & 5.2.4 at the three phase grid terminals.

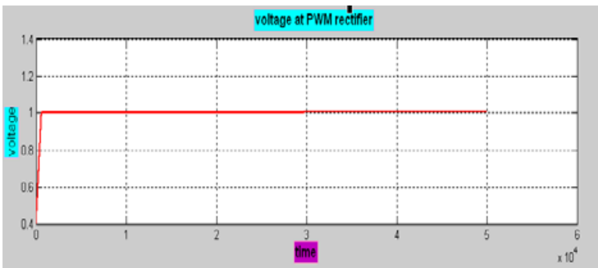


Fig 5.2.4. Voltage at PWM rectifier

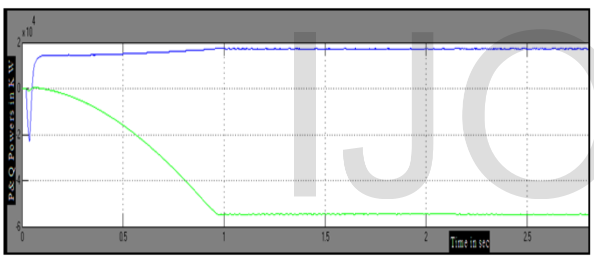


Figure 5.2.5 shows the active power (P), reactive power (Q) flows through the power system before wind turbine based distributed generation injection in to the system

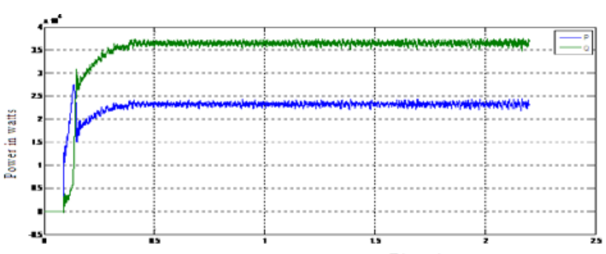


Figure 5.2.6 shows the reversal of active power (P) and reactive power (Q) flows in the power system after integration in the power system

6.Conclusions

This paper has presented an active and reactive power flow analysis of converters in wind turbine based distributed generation systems. Its proposed that necessity to use proper protective schemes to provide a pretty protection to the power system against the reversal of active power and reactive powers due to integration of wind turbine distributed generation and its Modeling and simulation results of a grid connected wind turbine DG systems are analyzed and presented in this paper using MATLAB/SIMULINK .

7. ACKNOWLEDGMENTS

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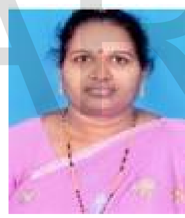

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