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Performance of FACTS Devices for Power System Stability

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Abstract

When a power grid is connected to an induction type wind electric generator (WEG), when there is variation in load and wind speed, grid voltage also varies. In this paper, we study what is the impact when there is a variation of load and wind by variation of real power and reactive power consumed by WEG effect of load and wind speed variations on real power supplied and reactive power consumed by the WEG as well as voltage on the grid are studied. The voltage variation in the grid is controlled by reactive power compensation using shunt connected Static VAR Compensator (SVC) comprising Thyristor Controlled Reactor (TCR) and Fixed Capacitor (FC). With the help of Fuzzy Logic Controller (FLC), TCR is operated automatically.

Keywords: *wind electric generator, thyristor controlled reactor, fixed capacitor, fuzzy controller, reactive power*

1. Introduction

In the present power scenario, the demand for electrical power is increasing and conventional resources are depleting fast. Recent studies indicate that there are substantial improvements in the utilization of renewable energy sources especially in the developing countries. This is because of the recent technological developments and also due to environmental and social considerations. Wind energy has experienced remarkable growth over the last decade due to renewed public support and maturing turbine technologies. Many wind turbines use a squirrel cage induction generator to produce electricity. These generators allow small variations in rotor speed thus reducing torque shocks caused by wind gusts [1]. However they absorb large amounts of reactive power and cause severe voltage stability problems on the grid. Traditional shunt compensation using fixed capacitors, due to varying load conditions on the grid and sudden wind gust, sometimes leads to large voltage fluctuations in the grid as the reactive power consumed by the WEG varies widely. So, FACTS devices such as SVC and STATCOM have been suggested as sources for reactive power support due to the ability of these to provide continuously variable susceptance and also the ability to react fast. This paper reports the voltage fluctuations on the grid connected to wind farms due to variations in wind speed and also in loads connected to the grid. The proposed voltage regulation scheme uses a Static VAR Compensator (SVC). SVC comprises a fixed capacitor in parallel with a Thyristor Controlled Reactor (TCR which in turn consists of a reactor in series with a pair of anti parallel thyristors, in each of the three phases.

By varying the firing angle of the thyristor,the fundamental reactive current drawn by the TCR and thereby the net reactive power contributed by the SVC is controlled [2].

2. Wind Electric Generator

A wind turbine is a device that converts kinetic energy from the wind into mechanical energy; a process known as wind power. If the mechanical energy is used to produce electricity, the device may be called a wind generator or wind charger. If the mechanical energy is used to drive machinery, such as for grinding grain or pumping water, the device is called a windmill or wind. Developed for over a millennium, today's wind turbines are manufactured in a range of vertical and horizontal axis types [3]. The smallest turbines are used for applications such as

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battery charging or auxiliary power on sailing boats; while large grid-connected arrays of turbines are becoming an increasingly large source of commercial electric power.

3. Static Var Compensator (SVC)

A static Var compensator (or SVC) is an electrical device for providin fast-acting reactive power on high-voltage electricity transmission networks. SVCs are part of the Flexible AC transmission system device family, regulating voltage and stabilizing the system. Unlike a synchronous condenser which is a rotating electrical machine, a "static" VAR compensator has no significant moving parts (other than internal switchgear) [4]. Thyristors in anti parallel are used to switch on a capacitor or reactor unit in stepwise control. When the firing angle of thyristors is varied the reactor unit acts as continuously variable in the power circuit. The SVC is an automated impedance matching device, designed to bring the system closer to unity power factor. SVCs are used in two main situations:

a) Connected to the power system, to regulate the transmission voltage ("Transmission SVC")

b) Connected near large industrial loads, to improve power quality ("Industrial SVC")

3.1. Thyristor Controlled Reactor

A thyristor-controlled reactor (TCR) is a reactance, which is connected in series with a bidirectional thyristor valve. The thyristor-controlled reactor is an important component of a Static VAR Compensator.

The thyristor valve is phase-controlled. In parallel with the circuit consisting of the series connection of the reactance and the thyristor valve, there may be an opposite reactance, usually consisting of a permanently connected, mechanically switched or thyristor switched capacitor [5]. By phase-controlled switching of the thyristor valve, the value of delivered reactive power can be set.

3.2. Fixed Capacitor

A capacitor of fixed value is connected in parallel to the network whose value depends upon the total reactive power that has to be supplied. In general instead of a single capacitor, a capacitor bank is employed so that the size of inductor can be smaller, reactive power injected can be regulated smoothly and the amount of ohmic power loss can be reduced.

3.3. Combined Fixed Capacitor – TCR

The fixed capacitor always supplies a constant reactive power (which is equal to the maximum reactive power consumed by the load) to the network. If the reactive power required in the network is lesser than that, the TCR is made to absorb the extra reactive power [6]. This is done by reducing the firing angle of the TCR. If the reactive power required becomes higher, the TCR is made to absorb less which is done by increasing the firing angle.

4. Fuzzy Logic Controller

Fuzzy logic is widely used in machine control. The term itself inspires a certain skepticism, sounding equivalent to "half-baked logic" or "bogus logic", but the "fuzzy" part does not refer to a lack of rigor in the method, rather to the fact that the logic involved can deal with fuzzy concepts—concepts that cannot be expressed as "true" or "false" but rather as "partially true" [7]. A fuzzy control system is a control system based on fuzzylogic—a mathematical system that analyzes analog input values in terms of logical variables that take on continuous values between 0 and 1, in contrast to classical or digital logic, which operates on discrete values of either 1 or 0 (true or false respectively).

5. Development of WEG Model

Cp-λ characteristics of the wind turbine, which is required to model the wind turbine can be obtained from the power curve of a WEG. Figure 1 shows the power curve of the 250kW WEG chosen for the study. Assuming the efficiency of the 250 kW induction generator as 90%, the turbine output is calculated as (250 /0.9) =277.78 kW [8]. The power output is constant from rated wind speed to cut off wind speed. Different values of wind speed in this range are used for calculating the values of Cp and λ.

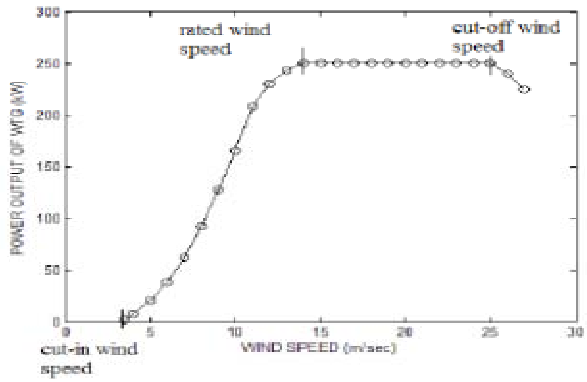

Figure 1. Power curve showing different ranges of wind speed

The Cp-λ graph thus evolved is then extrapolated based on the following assumptions:

a) The maximum Cp of the turbine = 0.45

b) The Nominal λ at which the corresponding Cp is at its maximum = 5

c) The value of λ at which Cp is zero =10.

Figure 2 shows the extrapolated graph. A polynomial expression of Cp in terms of λ is obtained from the graph using curve fitting methods and that is given in Equation (1).

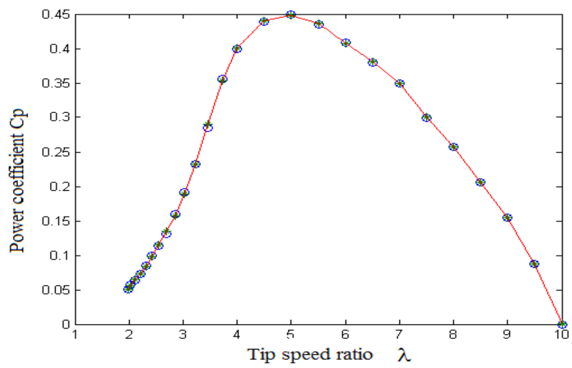

Figure 2. Graph deduced from the power curve

$$C_p = 0.00017\lambda^{10}-0.00033\lambda^{9}-0.00066\lambda^{8}+0.025\lambda^{7}-0.044\lambda^{6}-0.097\lambda^{5}+0.21\lambda^{4}+0.088\lambda^{3}-0.43\lambda^{2}+0.04\lambda+0.4 \quad (1)$$

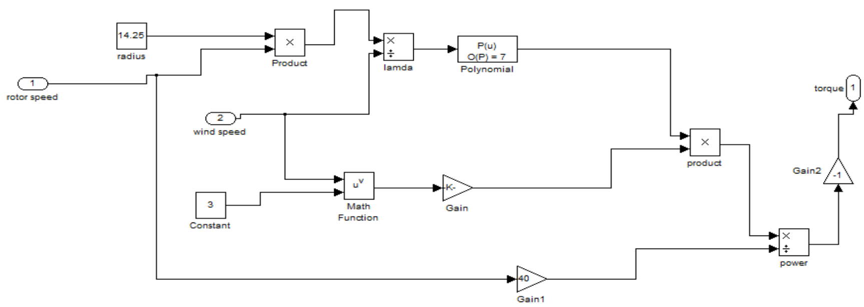

Figure 3. Simulink model of wind turbine

This expression is used in developing a simulation model of wind turbine. Figure 3 shows the Simulink model of the wind turbine.

6. Simulink Model of Wind Turbine

Figure 4 shows the system under consideration for the simulation study. The WEG is connected to the power Grid through a transmission line feeding RL load. Figure 5 shows the real power supplied by the grid (P), reactive power absorbed by the WEG (Q) and the grid voltage (V) for different wind speeds without compensation. It is to be noted that the maximum variations in P, Q and V are respectively 0.862 pu, 0.373 pu and 0.021 pu between 7 m/s and 23 m/s. Grid voltage varies from 387V to 378.6V. P and Q vary from 31.95kW to 230.8kW and 61.78kVAR to 98.58kVAR respectively. It is found that the maximum reactive power absorbed by the WEG is 1pu (98.58kVAR) at 14m/s. This is supplied by the reactive power source at the sending end.

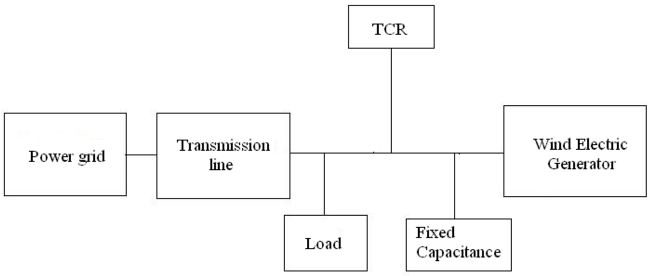

Figure 4. Block Diagram of Wind Electric Generator connected to grid with FC and TCR

7. Block Diagram

Figure 6 shows the variation in grid voltage due to change in load conditions when the wind speed is kept constant at 14m/sec. It is observed that there is a substantial change of 0.051pu in grid voltage for the load change from 35% to 115%. Grid voltage varies from 414.7V to 394.5V. The results of the study made so far established that FC compensation improves grid voltage substantially, yet it cannot maintain grid voltage constant when there is variation either in wind Speed or in the load demand. Use of TCR along with FC can regulate grid voltage more precisely.

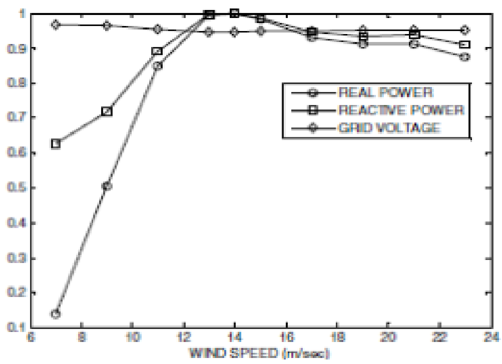

Figure 5. Real power, reactive power for different wind speed

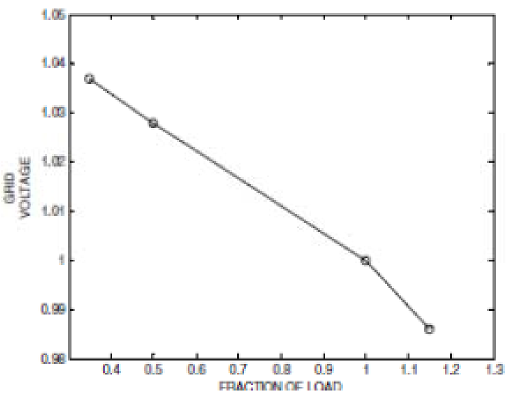

Figure 6. Variation in Grid voltage due to change in load conditions

8. Firing Pulse Generation for TCR

From the above results, it is observed that due to variations in the wind speed and load, the reactive power consumption and therefore the grid voltage varied. For complete and smooth compensation the reactive power supplied should vary as the Q demand. But the reactive power supplied by FC cannot vary. Therefore a three phase star connected Thyristor Controlled Reactor (TCR) is designed and connected at PCC. TCR absorbs the excess reactive power supplied by the Fixed Capacitor (FC). Figure 4 shows the block diagram of WEG connected to Grid with FC and TCR. Whenever there is a change in the Q demand, the firing angle of the TCR has to be varied accordingly in order to maintain the grid voltage constant. To achieve this automatically, Fuzzy Logic Controller (FLC) is implemented. The controller needs to have only one input which is the grid voltage and the single output, which is the firing angle of TCR.

9. Simulation Circuit of the Complete System with Fixed Capacitor

Figure 7 shows the simulation circuit of the complete system with fixed capacitor. In this by varying the capacitor value reactive power, grid voltage & real power of the system is compensated. Figure 8 shows the graph reactive power Vs wind speed, real power Vs wind speed & grid voltage Vs wind speed. As such we change the value of capacitor reactive power of the system change. Figure 8 shows the output of real power, reactive power, & grid voltage i.e. 1.346, 134.6, 211.9. respectively at wind speed 16 m/s. It show that after some fluctuation grid voltage & power in system is constant.

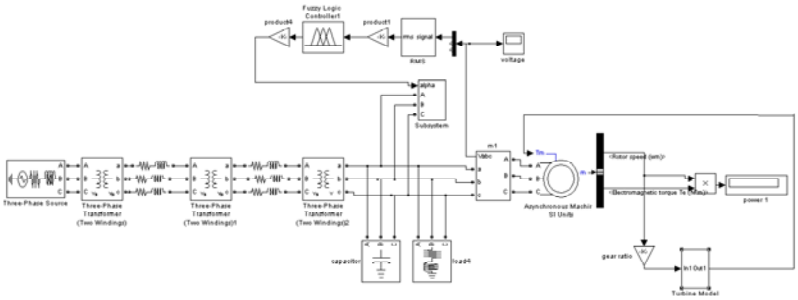

Figure 7. Simulation circuit of the complete system with fixed capacitor

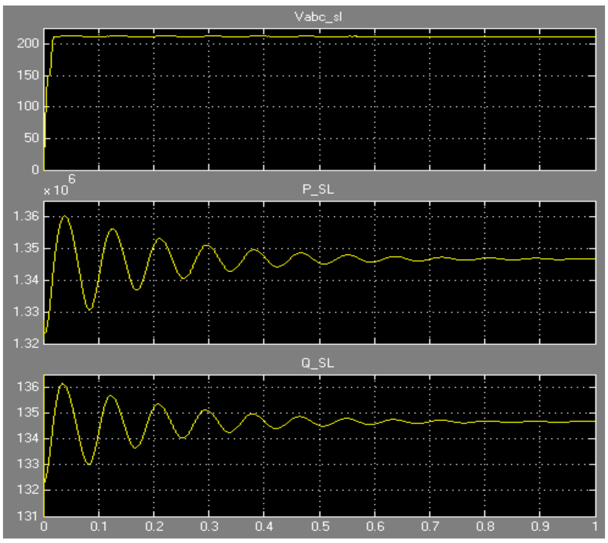

Figure 8. Output of Real Power, Reactive Power, & Grid Voltage

Figure 9 shows the out of real power, reactive power & grid voltage i.e. 1.347 VAR, 134.2, & 212 Volt at wind speed 20 m/s. when the value of capacitor change i.e. increase compensate reactive power is generated in the system.

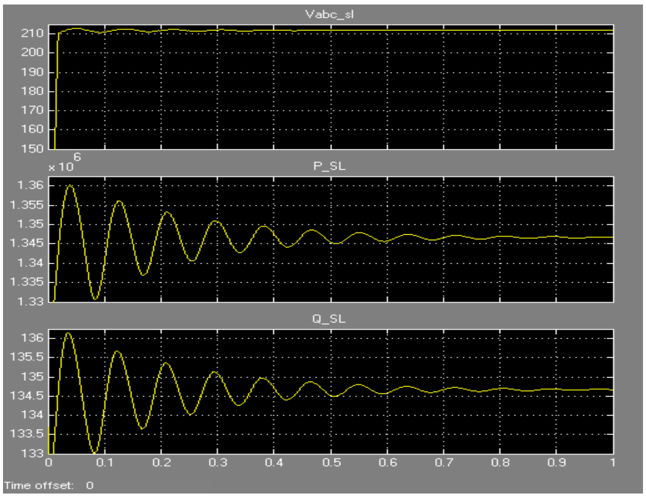

Figure 9. Output of real power, reactive power, grid voltage

10. Conclusion

A methodology to investigate the wind power influences on the power system was presented in this thesis. It includes analysis of the wind power influences on the voltage stability, power system stability and power quality characteristics. The voltage stability was analysed with load ability curves to the power system. The voltage stability was influenced by the wind power integration, where the reactive power was the main factor. A load ability computation tool was developed in this thesis and a static model to the wind power on the voltage stability was presented. Modifications of the wind turbine characteristics, i.e. application of power electronics, were simulated improving the voltage stability. The main conclusions for the voltage stability are that although the wind power alleviates the active power fluxes in the network, the reactive power flux to the wind farms will reduce the voltage stability limits. Wind turbine technologies with power converters that can actively control the reactive power consumption increased the voltage stability (i.e. extended the power limit of the voltage collapse) of the power system. The power system stability and power quality were investigated with dynamic simulations.

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