Active and Reactive Power Control Through P-Q Controller Base System to Replicate the Behavior of Full Power Converter of Wind Turbine

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Abstract— This paper presents a technique to simulate the active and reactive power control phenomenon of a full power converter base wind turbine. The implementation of full power converter in the wind turbine has enhanced the quality of power supply to the grid. It has the ability to increase better controllability and full control over real and reactive power. The active and reactive powers are the essential area of control for the grid manager. The conventional energy generation companies provide some margin of reactive power support with the active power to the grid. But for the case of renewable energy producers it is the matter of concern. In this paper a P-Q controller is introduced for controlling active and reactive power of the full power converter base wind turbine which injects power to the PCC. The design technique implements PI controller base system with externally control current source. The simulation model has been prepared in PSCAD/EMTDC.

Keywords— P-Q controller, Point of common coupling (PCC), Transmission system operator (TSO), Grid code, Full power converter**,** voltage source converter (VSC)**.**

INTRODUCTION

The driving force of a society is the development of its energy producing infrastructure. As the world is advancing day by day, eventually it is essential to find new sources of energy to meet the future energy demand. It cannot be based solely on the conventional sources of energy such as thermal, nuclear and hydro power, because of the rapid decline of the sources and their impact on the environment is quite alarming for the society. To find the better solution modern, energy technology is moving towards the renewable energy sources i,e wind, solar and wave energy . So far, their contribution to meet demand is quite modest. The main disadvantages of these renewable energy sources that they are quite expensive and less flexible compared to conventional power plants. But their enormous potential to collect from nature and environment friendly characters make them the alternative choice for the future energy. Currently the most effective wind power plants have efficiency of about 50% and now the consideration is to make it cheaper, more reliable and more flexible [1]. The technological development of wind power is vast in Europe, America and some of the countries of Asia like India and China. To make the renewable energy sources to perform well and overcome their limitation, the major challenge is the efficient integration with the conventional grid. The characters of the conventional energy sources are known to the system operators but the behaviors of the renewable energy sources are quite unpredictable because they directly rely on nature, suppose for the case of PV shell it depends on sun irradiation and for wind energy it depends on the wind speed, which has a variation on hour to hour, day to day and also month to month basis. The system operators expect that these renewable energy sources should provide some control over the active and reactive power, which is included in the grid code for them.

Control over active power and reactive power in steady state and in the time of system dynamics are the area of concern. But with the help of modern technology the full power converter base system of the wind turbine can overcome this problem.

In this paper a simple way is presented to represent the real and reactive power effect to simulate the behavior of wind turbine in providing real power to the grid and in some case the reactive power support to the grid. A P-Q controller base system is presented to simulate the active and reactive power control phenomenon of a full power base wind turbine both in normal and abnormal condition of the grid.

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Electric grids are basically two types, which are ac grid and dc grid. In a dc grid the total power is calculated from active power, which is the multiplication of voltage and current. The conduction loss depends only on the active power.

For the case of conventional ac grid the total power is calculated through its apparent power, which is the geometric sum of active and reactive power [8]. In an AC grid the voltage and current both are sinusoidal quantities which oscillate with the frequency of 50 or 60 hz. The product of these two will be the power and it will be only the active power if there is no phase difference between the voltage and current. However, if there is any phase shift between the voltage and current the output power is oscillating with its positive and negative value [8]. If the phase difference between current and voltage is 90 then the total power is the reactive power because the active power is oscillating with equal and opposite value and the average of active power is zero. This situation can arise, if the system is dealing with pure inductive or capacitive element. For the case of pure inductive element the current lags behind the system voltage by 90 and in the case of pure capacitive element the current leads the voltage by 90.

If a transmission grid is considered, where it is connected to renewable energy source like wind turbine, there exists reactive components with the resistive components for the line. Now if a transformer is presented in between the generating source and the grid, it also has inductive reactance. On the consumer side of the load are mostly inductive. So for the grid it is essential to prepare the compensation arrangement for reactive power, because the reactive power is not consumed by the load it just go forward and backward in the system and just participate in the system conduction loss. That's why the compensation is required. Generally the big generating station supply active power with leading power factor that means they have reactive power compensation for the inductive load. To compete with the conventional energy sources the wind firms also have to provide support for the reactive power, which is imposed by the transmission system operators (TSO) through the grid code criteria.

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The improvement and modification of modern technology has helped a lot to develop some essential fetchers of wind turbine like the size, quality of output power and technology used. One of the most important improvements is the development of full power converter with variable speed operation. In a full power converter base wind turbine the generator may be a permanent magnet synchronous generator or an induction generator. They may or may not use gear box as shown in the Figure -1. The energy produced in this kind of wind turbine passes through the converter, so it can isolate the system in the time of major disturbance of the grid. With the variation of wind speed the electrical frequency of the generator can change otherwise the power frequency in the grid remains unchanged. Thus allow the variable speed operation of the wind turbine [3].

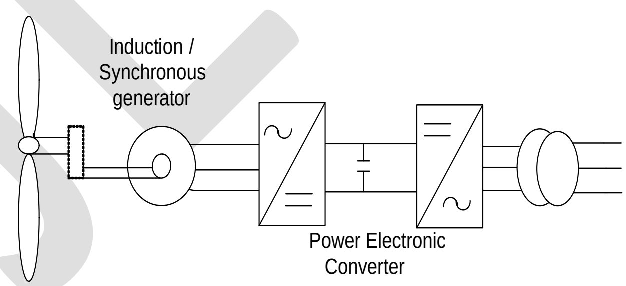

Figure-1 Full power converter base wind turbine[5].

A full power converter is consisting of two voltage source converter, one is responsible two control the generator side and the second one is responsible for the grid side. Each of the converters has the ability to absorb or generate the reactive power independently [7]. The generator side converter is basically a diode rectifier or a Pulse width modulated converter, where as the grid side converter is a conventional PWM converter [3]. The output power from the generator depends on the rotor speed which depends on wind speed. The wind speed has a wide variation and the rotor speed also varies with it as shown in figure-2, a controllable output power is possible by the rotor side converter which helps the rotor to adjust its speed. Whereas the grid side converter provide a controllable active power output without consuming reactive power, Rather than it has the ability to provide some reactive power it needed by the grid [4].

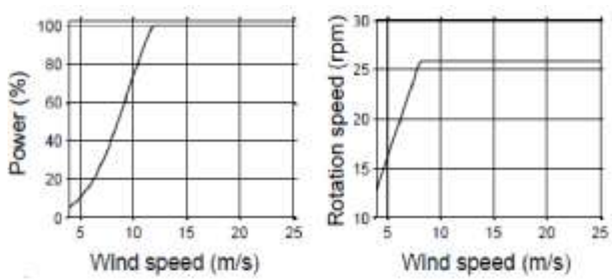

Figure-2 Power and Rotor speed curve with respect to wind speed.

DESIGN OF THE SYSTEM

A P-Q controller based system is designed to replicate the behavior of a full power converter considering the nature of wind turbine and how it behaves with the connected grid. The essential features of the P-Q controller are the control over the active power which is performed by the generator side converter and the control over the reactive power which is performed by the as the grid side converter. Thus by using a P-Q controller the full power converter base wind turbine can be eliminated from the network during the time of grid code analysis simulation work to make the system more simple.

As mentioned before, the wind power generation varies with the wind speed, so it is expected that at PCC of grid power injection in a controlled way. The task can be performed by the grid side converter of full power converter. In this designed model the reference value of active and reactive power is set at PCC and it is expected that the turbine side converter should achieve the value by its controllability [5]. The P-Q controller can exchange a given amount of real and reactive power at the point of common coupling. Figure-3 shows the connection of load to the PCC [5].

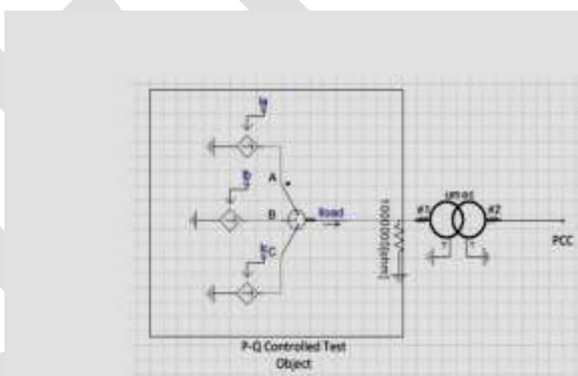

Figure-3 Externally control current source [5].

At the PCC the voltage is to be maintained constant, so the power at that point can be controlled by controlling the current through that point or vice verse. The design block is shown in figure-4.

The entire system can be presented by the block diagram as shown in figure-5. It can be divided in to the following blocks:

- .ecruos tnerruc lortnoc yllanretxE
- .tnemerusaem egatlov esahp 3
- .tnemerusaem rewop evitcaer dna evitcA

- .kcolb LLP
- .retrevnoc tnerruc esahp3 ot βα dna βα ot qd
- .rellortnoc Q-P

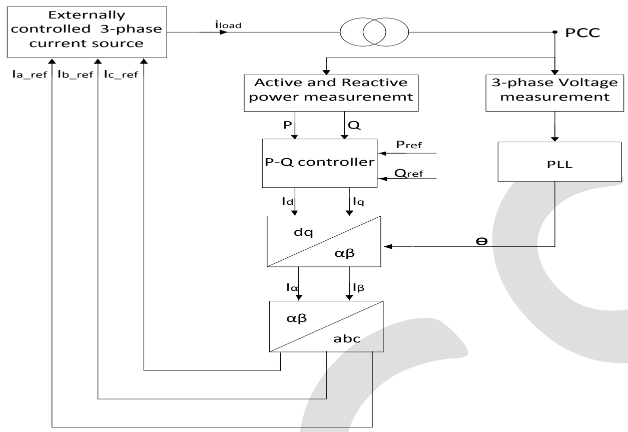

Figure-4 Block representation of the system [5] .

EXTERNALLY CONTROL CURRENT SOURCE

Externally control current source is a kind of current source which responds with the reference current .That means if a 3 phase reference current is set, it generates a value of 3 phase load current. The reference current is output of the controller.

PHASE VOLTAGE MEASUREMENT

The three phase voltage is measured at the PCC through the 3 phase Voltage measurement block. It is essential for the conversion process in the PLL block which is described later part.

ACTIVE AND REACTIVE POWER MEASUREMENT

Active and reactive power measurement block sense actual power at PCC which is used as the actual value of P and Q which compare with the reference value of active power P_{ref} and reactive value of power Q_{ref} is respectively.

PHASE LOCK LOOP (PLL)

The output of the P-Q controller is the d-q component of current which is described later part of P-Q controller. But the reference in the externally control current block is the 3 phase current. According to [6] the d-q current is converted in to the 3 phase current using the d-q to αβ conversion, so called Park's transformation and then αβ to 3 phase current conversion, so called Clark's transformation. For converting d-q to alpha-beta voltage angle theta is needed. So to find out the angle theta PLL (Phase lock loop) is introduced.

There are basically two types of PLL arrangement. One of them is voltage oriented PLL, in which the voltage vector is aligned with the d- axis and the q-axis component is equals to zero. The other type of PLL is the Flux oriented PLL, where the voltage vector is aligned with the q-axis component and d-axis component is equals to zero. This type of PLL is normally used in controlling the Electric drives. The Voltage oriented PLL is used in the Transmission and Distribution system. The point of consideration in this paper is the voltage at PCC so the voltage oriented PLL is used in this case.

The figure 5 shows the block diagram and Figure-6 shows the vector diagram of voltage oriented PLL. The controller is voltage oriented, so PLL makes Vq=0, during steady state operation it locks the controller phase voltage with the phase voltage of PCC [6].

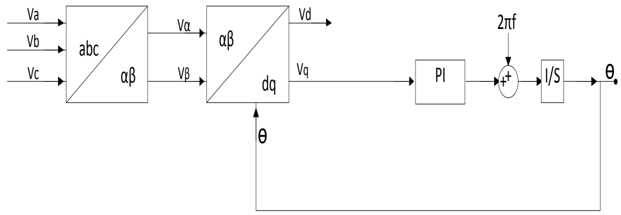

Figure-5 Design of PLL [5].

The transfer function of the PI controller is taken from [6].

$$F_{c,PLL} = k_{p,PLL} + \frac{k_{i,PLL}}{s} \qquad (1)$$

Where the proportional gain $k_{p,PLL}=2\alpha$ and the integrator gain $k_{i,PLL}=\alpha^2$ taken from [2]. The bandwidth $\alpha= 2\pi f_{PLL}$ and f_{PLL} is chosen as 5 Hz the slow PLL is used for the design.

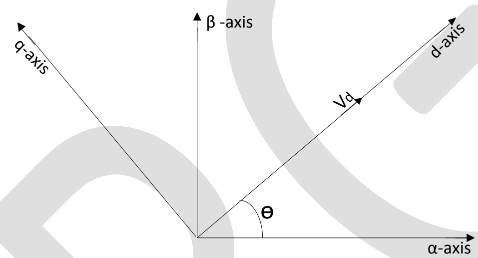

Figure-6 Voltage oriented PLL vector diagram [5].

P-Q CONTROLLER

To design the control mechanism of the P-Q controller the PI controller has been selected because it is simple and the rating of current and voltage is not the matter of concerned [5].The system is considered power invariant, so the equation for active and reactive power equation in d-q frame can be written in the following way,

$$P = v_d i_d + v_q \qquad (2)$$

$$Q = v_q i_d - v_d i_q \qquad (3)$$

As the PLL used in the system is voltage oriented the q-axis component of voltage is zero so the equation becomes,

$$P = v_d i_d \qquad (4)$$

$$Q = -v_d i_q \qquad (5)$$

The active and reactive power can be controlled by making the voltage at PCC stagnant, so the current is the only quantity in equation (4) and (5) that is needed to be controlled. The reference values are the chosen value of active and reactive power where as the actual values are measured from PCC. Then the error signals which passes through the PI controller are generated by comparing these two sets of values for both the cases of active power and reactive power. So the current I_d can be found the active power controller and the equation of current is,

$$i_d = (P_{ref} - P)F_c \qquad (6)$$

Where the voltage V_d is desired to be 1 p.u .

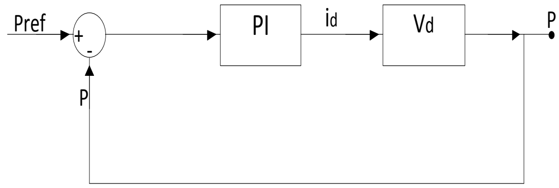

Figure-7 Block diagram of active power controller [5] .

The expression of the transfer function Fc of the PI controller can be written as,

$$F_c = \left(k_p + \frac{k_i}{s}\right) = k_p\left(1 + \frac{1}{ST_s}\right) \qquad (7)$$

So from the equation (7), if the value of the proportional gain k_p and the time constant of the integrator constant T_s are known, then one can calculate the value of F_c [6].

The value of the gain k_p=0.97 and time constant T_s has chosen is 200ms through hit and trial method [6] which can be seen from figure- 9.

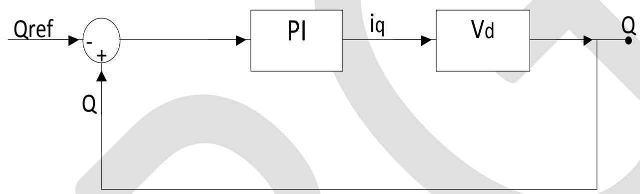

Figure-8 Block diagram of reactive power controller [5] .

Same parameters is used to design the reactive power controller and the i_q current is found from the controller.The current equation can be written as, $i_q = -(Q_{ref} - Q)F_c$ (8)

The current is in d-q system which is then converterd into αβ current and then 3-phase reference current of the externally control current source as shown in the Figure-3.

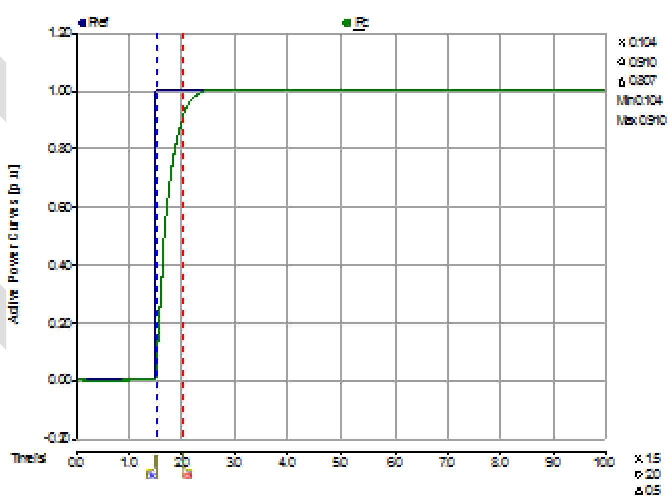

Figure-9 Active power curve[5].

CONCLUSION

A full power converter based wind turbine is capable of providing the active and reactive power support to the grid which can be tested through the simulation model. To test the wind turbine grid code requirements a simple P-Q controller base simulation model can be used instead of using the whole model of full power converter base wind turbine. A P-Q controller base system is very smile in construction which represents the system in a simplified way, which uses the PI controller base system. For a PI controller current rating is not the matter of concern. So using the controller the Active and reactive base controller can be modeled which replicates the behavior of the wind turbine essential for the simulation work.

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