Reactive Power Improvement in Wind Farm by Using UPQC

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Abstract: ***At present, wind energy generation, utilization and its grid penetration is increased in worldwide. But wind generation is fluctuating due to time varying nature and causing stability problems. This weak interconnection affects the power quality and reliability. In order to improve the power quality in wind farm like voltage sag and swell, Reactive power compensation , voltage regulation by using the power electronics devices such as SVC, STATCOM, SSSC, UPFC etc.,. FACTS Controllers provide the necessary dynamic reactive power support and the voltage regulation. Even utilizing these controllers in power system, voltage regulation problems are arised at the point of common coupling (PCC). To overcome these problems a compensate technique will be used at PCC. The Custom Power devices technology (CPDT) efficiently regulates all problems in distributed levels. In this project propose a Unified Power Quality Compensator or Conditioner (UPQC) to regulate the Voltage in the WF terminals and to improve reactive power at transmission and distributed from grid side. The internal control strategy is based on the management of active and reactive power in the series and shunt converters of the UPQC, and the exchange of power between converters through UPQC DC–Link. MATLAB / SIMULATION results show the effectiveness of the propose compensation strategy for the enhancement of reactive power improvement in Power Quality concept.***

Keyword: DFIG, Reactive Power in system, UPQC, UPQC control strategy, Simulation results

1. Introduction

The world's energy resources are not sufficient to sustain expected growth trends. A growing gap is developing between energy demand and the available supply of oil and gas. Wind energy has shown the fastest growth rate of any form of electricity generation with its development simulated by the concerns of climate change, energy diversity and security of supply in past few decades [1]. Owing to on-going improvements in turbine efficiency and higher fuel prices, wind power is becoming economically competitive with conventional power production, and at sites with high wind speeds on land, wind power is considered to be fully viable. The large scale penetration of wind energy in the electrical network systems is consistently imposing challenges to the engineers due to the proportionate advancement of technology and provides an increasing evidence of the influence between wind farms and the grid. Today large-scale integration of wind sources into the grid via full-power converters is being increasingly adapted due to its high power density and controllability [3]. With variable-speed wind turbines, the sensitivity of the power electronics to over currents caused by network voltage depressions can have serious consequences for the stability of the power system. Thus, the control system of each individual turbine should be connected to a supervision system that supervises the operation situation and power regulation of the whole wind farm. This supervision system also fetches operation data from grid regulation system of the whole wind farm and reactive power requirements. A general topology of such a control system of a wind farm comprising of Full Power Converter wind turbines is shown in Figure 1.

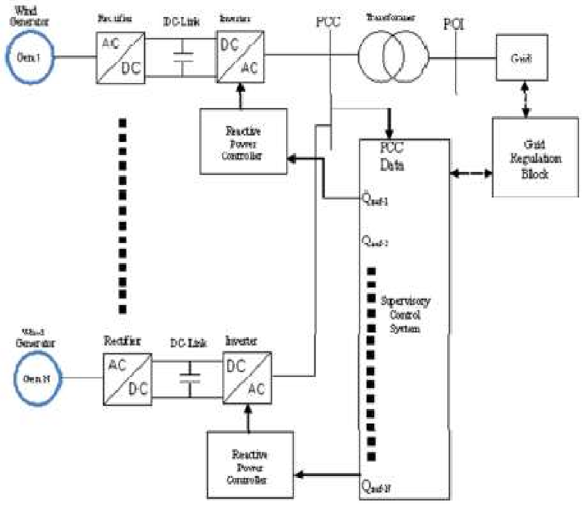


Figure 1: General Topology of Wind Farm –Reactive power Control system

1.1. Wind Energy-Generation Systems

Utilization of the wind energy has been a historic concept. However, these wind power conversion systems behave different, in comparison to the conventional power plants, when connected to the grid In this chapter, the modern wind power plants and then briefly compares the wind power plants with that of the conventional power plants will be analysed [2]. The theoretical power generated by the WTG is expressed as:

$$P = \frac{1}{2} C_p \rho V^3 A$$

Where P = power [W]
Cp = power coefficient
ρ = air density (1.225 kg/m3)
 V = wind velocity (m/sec)

A = swept area of rotor disc (m2)

It is not possible to extract all kinetic energy of wind, thus it extract a fraction of power in wind, called power coefficient Cp of the wind turbine, and is given in equation

$$Pmech = CpPwind$$

2. Doubly Fed Induction Generator (DFIG) Wind Turbine

A typical configuration of a DFIG wind turbine is shown schematically in Figure 2. It uses a Wound Rotor Induction Generator (WRIG) with slip rings to take current into or out of the rotor winding and variable-speed operation is obtained by injecting a controllable voltage into the rotor at slip frequency.

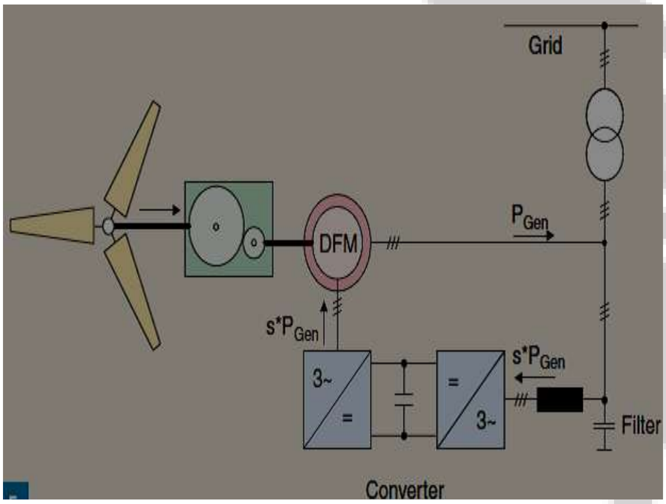


Figure 2: DFIG with Wind Turbine

The rotor winding is fed through a variable-frequency power converter, typically based on two AC/DC IGBT-based voltage source converters (VSC) linked by a DC bus. The power converter decouples the network electrical frequency from the rotor mechanical frequency, enabling variable-speed operation of the wind turbine. The generator and converters are protected by voltage limits and an over-current 'crowbar'. A DFIG system can deliver power to the grid through the stator and rotor, while the rotor can also absorb power, depending on the rotational speed of the generator [4].

2.1. DFIG Vector Control

To guarantee stable operation and enable independent control of active and reactive power of the DFIG, a model-based feed-forward controller is developed using the dynamic model equations mentioned above. A block diagram is shown in Figure 3. Fundamentally, the proposed controller is a vector controller, because the synchronous reference frame in which the machine equations are described is linked to the stator voltage space vector v s and not to the stator or rotor flux vector, as is common in field-oriented controllers for drives [4].

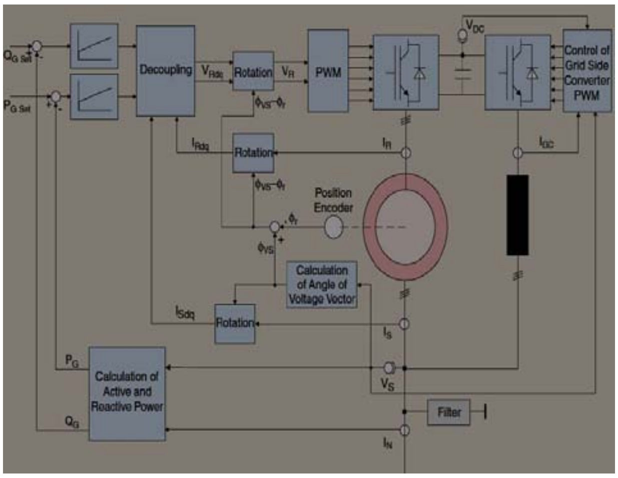


Figure 3: DFIG – Vector Control Diagram

3. Reactive Power System

In practice, it reduces reactive power to improve system efficiency. This is acceptable at some level. If system is purely resistively or capacitance it make cause some problem in Electrical system. Alternating systems supply or consume two kind of power: real power and reactive power. Real power accomplishes useful work while reactive power supports the voltage that must be controlled for system reliability. Reactive power has a profound effect on the security of power systems because it affects voltages throughout the system. Voltage control in an electrical power system is important for proper operation for electrical power equipment to prevent damage such as overheating of generators and motors, to reduce transmission losses and to maintain the ability of the system to withstand and prevent voltage collapse. Decreasing reactive power causing voltage to fall while increasing it causing voltage to rise. A voltage collapse may be occurs when the system try to serve much more load than the voltage can support [6].

3.1. Necessary to Control of Voltage and Reactive Power

Voltage control and reactive power management are two aspects of a single activity that both supports reliability and facilitates commercial transactions across transmission networks. On an alternating current (AC) power system, voltage is controlled by managing production and absorption of reactive power. There are three reasons why it is necessary to manage reactive power and control voltage. First, both customer and power system equipment are designed to operate within a range of voltages, usually within±5% of the nominal voltage. At low voltages, many types of equipment perform poorly, light bulbs provide less illumination, induction motors can overheat and be damaged, and some electronic equipment will not operate at. High voltages can damage equipment and shorten their lifetimes. Second, reactive power consumes transmission and generation resources. To maximize the amount of real power that can be transferred across a congested transmission interface, reactive power flows must be minimized. Similarly, reactive power production can limit a generator's real power capability. Third, moving reactive power on the transmission system incurs real power losses. Both capacity and energy must be supplied to replace these losses.

4. UPQC

Unified power quality conditioners (UPQC) allow the mitigation of voltage and current disturbances that could affect sensitive electrical loads while compensating the load reactive power. Unified power quality conditioners (UPQC) consist of combined series and shunt active power filters for simultaneous compensation of voltage and current disturbances and reactive power [10].

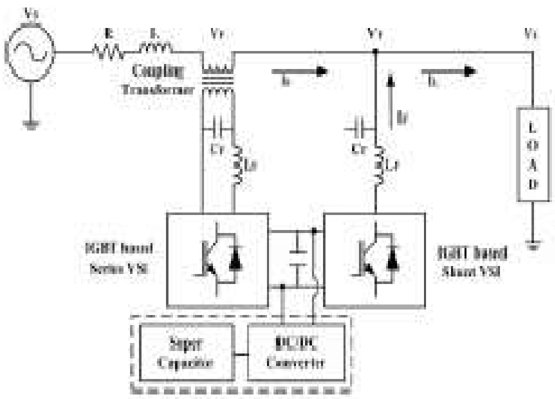


Figure 4: Basic structure of UPQC

4.1. Equivalent circuit- UPQC

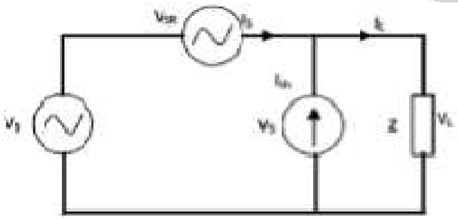


Figure 5: Equivalent circuit of UPQC

VS: Voltage at power supply
VSR: Series-APF for voltage compensation,
VL: Load voltage and
ISh: Shunt-APF for current and VSR compensation.

Due to the voltage distortion, the system may contain negative phase sequence and harmonic components. In general, the source voltage in Figure 10 can be expressed as:

$$Vs + VSR = VL$$

5. DFIG WT with UPQC

The reactive power improvement in wind farms can be achieved by UPQC device. In this work, the DFIG provided with UPQC unit Matlab/Simulink system. The dynamic compensation of voltage variations is performed by injecting voltage in series and active–reactive power in the (PCC) busbar; this is accomplished by using an unified type compensator UPQC. The basic outline of this compensator; the busbars and impedances numbering is referred. The operation is based on the generation of three phase voltages, using electronic converters either voltage source type (VSI–Voltage Source Inverter) or current source type (CSI–Current Source Inverter). VSI converters are preferred because of lower DC link losses and faster response in the system than CSI. The shunt converter of UPQC is responsible for injecting current at PCC, while the series converter generates voltages between PCC and U1[11,12]. An important feature of this compensator is the operation of both VSI converters (series and shunt) sharing the same DC–bus, which enables the active power exchange between them. A typical configuration of a DFIG wind turbine is shown schematically in Figure 6. It uses a Wound Rotor Induction Generator (WRIG) with slip rings to take current into or out of the rotor winding and variable-speed operation is obtained by injecting a controllable voltage into the rotor at slip frequency [12, 13].

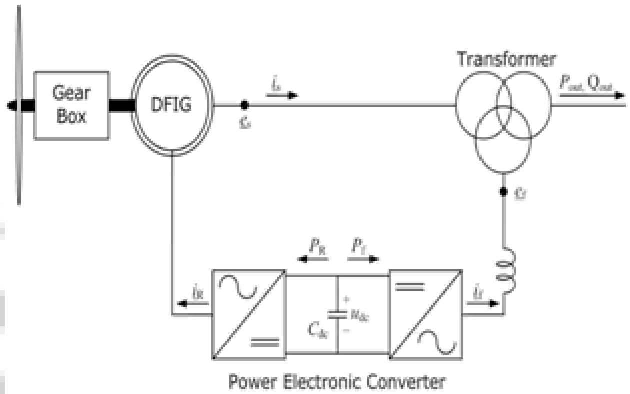


Figure 6: General Topology- DFIG WT with UPQC

The rotor winding is fed through a variable-frequency power converter, typically based on two AC/DC IGBT-based voltage source converters (VSC) linked by a DC bus. The power converter decouples the network electrical frequency from the rotor mechanical frequency, enabling variable-speed operation of the wind turbine. The generator and converters are protected by voltage limits and an over-current 'crowbar'. A DFIG system can deliver power to the grid through the stator and rotor, while the rotor can also absorb power, depending on the rotational speed of the generator.

5.1 UPQC Operation

The Figure 7 illustrates a conceptual diagram of this mode of operation. It must be remarked that the absence of an external DC source in the UPQC bus, forces to maintain zero–average power in the storage element installed in that bus. This is accomplished by a proper design of DC voltage controller. Also, it is necessary to note that the proposed strategy cannot be implemented using other CPD devices like D– Statcom or DVR. The current sources are explained with help of phasor diagram[15,16]

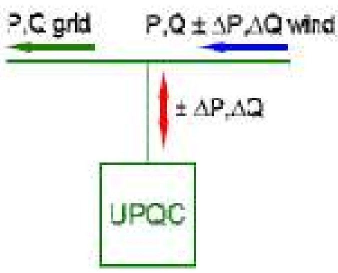


Figure 7: Basic operation of UPQC

5.2 Phasor Diagram

The operation is based on the generation of three phase voltages, using electronic converters either voltage source type (VSI–Voltage Source Inverter) or current source type (CSI–Current Source Inverter). VSI converters are preferred because of lower DC link losses and faster response in the system than CSI. The shunt converter of UPQC is responsible for injecting current at PCC, while the series converter generates voltages between PCC and U1, as illustrated in the phasor diagram (Figure 8).

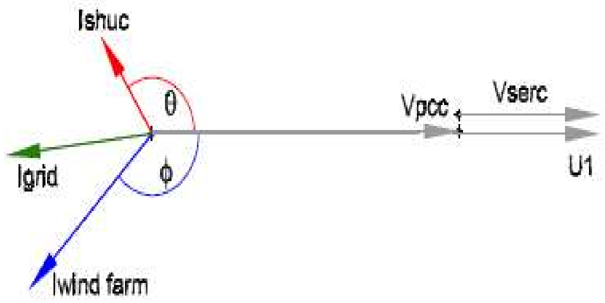


Figure 8: Phasor Diagram- UPQC

5.3 UPQC Control Strategy

The UPQC serial converter is controlled to maintain the WF terminal voltage at nominal value (see U1 bus-bar), thus compensating the PCC voltage variations. In this way, the voltage disturbances coming from the grid cannot spread to the WF facilities. As a side effect, this control action may increase the low voltage ride– through (LVRT) capability in the occurrence of voltage sags in the WF terminals [10, 13].

5.3.1 Series Converter Controller

A figure 9 shows series converter controller. The injected voltage is obtained subtracting the PCC voltage from the reference voltage, and is phase–aligned with the PCC voltage. On the other hand, the shunt converter of UPQC is used to filter the active and reactive power pulsations generated by the WF. Thus, the power injected into the grid from the WF compensator set will be free from pulsations, which are the origin of voltage fluctuation that can propagate into the system. This task is achieved by appropriate electrical currents injection in PCC. Also, the regulation of the DC bus voltage has been assigned to this converter.

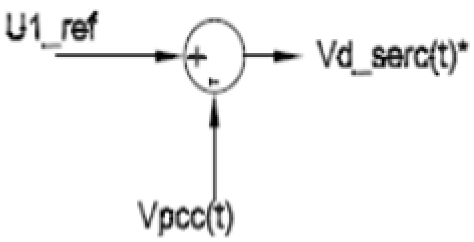


Figure 9: Series converter-UPQC

5.3.2 Shunt Converter Controller

This controller generates both voltages commands EshuC∗ and EqshuC∗ based on power fluctuations P and Q, respectively. Such deviations are calculated subtracting the mean power from the instantaneous power measured in PCC. The mean values of active and reactive power are obtained by low–pass filtering, and the bandwidth of such filters are chosen so that the power fluctuation components selected for compensation, fall into the flicker band as stated standard. In turn, EdshuC∗ also contains the control action for the DC–bus voltage loop. This control loop will not interact with the fluctuating power compensation, because its components are lower in frequency than the flicker–band.

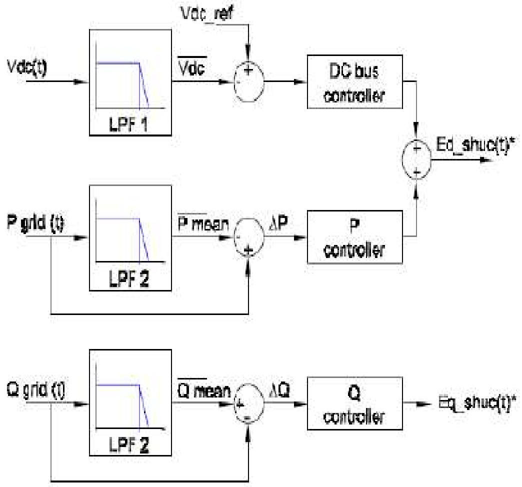


Figure 10: Block diagram-shunt converter

The powers PshuC and QshuC are calculated in the rotating reference frame, as follows:

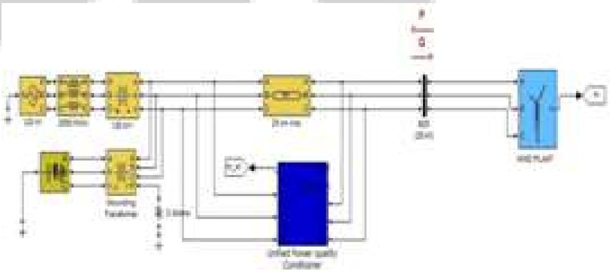
PshuC (t) = 3/2 * VPCCd (t) *IshuCd (t)
QshuC (t) = −3/2 * VPCCd (t) * IshuCq (t)
Ignoring PCC voltage variation, these equations can be written as follows.
PshuC (t) = k′p * Id shuC(t)
QshuC (t) = k′q * IqshuC(t)

Taking in consideration that the shunt converter is based on a VSI, we need to generate adequate voltages to obtain the currents. This is achieved using the VSI model proposed leading to a linear relationship between the generated power and the controller voltages. The equations are:

PshuC (t) = k″p * Ed shuC(t)
QshuC (t) = k″q * EqshuC(t)

P and Q control loops comprise proportional controllers, while DC–bus loop, a PI controller. In summary, in the proposed strategy the UPQC can be seen as a "power buffer", levelling the power injected in to the power system grid.

6. Simulation Model



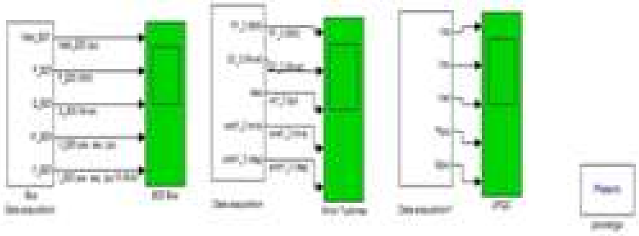


Figure 11: UPQC in Wind Farm- Simulation- Main circuit model

7. Results

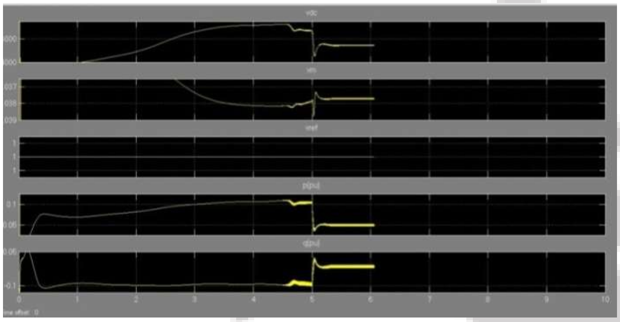


Figure 12: Active and Reactive power improvement with UPQC

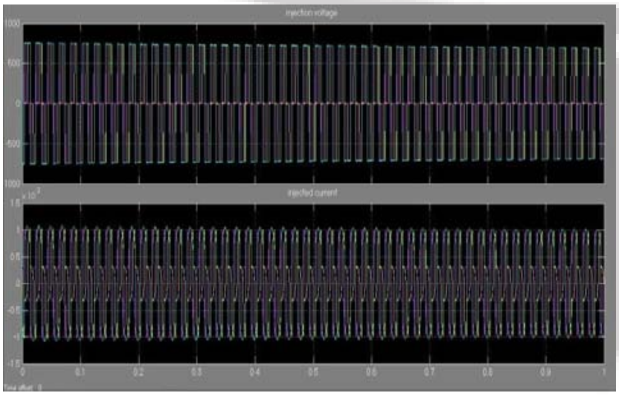


Figure 13: Injected Voltage and Current in UPQC

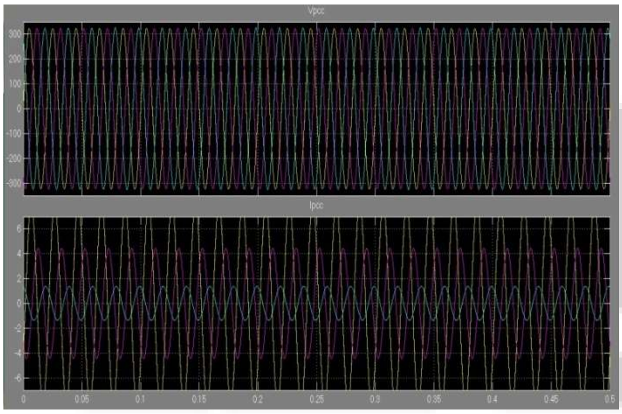


Figure 14: Voltage and current at PCC

8. Conclusion and Future Work

In this paper, a new compensation strategy implement using an UPQC type compensator is present to connect DFIG based wind farms to weak distribution power grid. The proposed compensation scheme enhances the system power quality, exploiting fully DC–bus energy storage and active power sharing between UPQC converters, features not present in DVR and D–Statcom compensators. The simulation results will show a good performance in the rejection of power fluctuation due to "tower shadow effect" and the regulation of voltage due to a sudden load connection. So, the effectiveness of the proposed compensation approach is demonstrated in the distributed area. In future work, performance comparison between different compensator types will be made. Commercial products have started to appear in the market to increase the renewable energy system connectivity by compensating some of the problem.

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