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Power Quality Improvement by UPQC Device in Wind Farm to Weak Grid Connection

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Abstract: The location of generation facilities for wind energy is determined by wind energy resource availability, often far from high voltage (HV) power transmission grids and major consumption centres. Wind Farms (WF) employing squirrel cage induction generator (SCIG) directly connected to the grid; represent a large percentage of the wind energy conversion systems around the world. In facilities with moderated power generation, the wind farms are connected through medium voltage (MV) distribution headlines. A situation commonly found in such scheme is that the power generated is comparable to the transport capacity of the grid. This case is known as Wind Farm to Weak Grid Connection, and its main problem is the poor voltage regulation at the point of common coupling (PCC). Thus, the combination of weak grids, wind power fluctuation and system load changes produce disturbances in the PCC voltage, worsening the Power Quality and WF stability. This situation can be improved using control methods at generator level, or compensation techniques at PCC. In case of wind farms based on SCIG directly connected to the grid, is necessary to employ the last alternative. Custom power devices technology (CUPS) result very useful for this kind of application.

Keywords: Wind Energy, Wind Farm.

I. INTRODUCTION

The main feature of the weak grid connection is increased voltage regulation sensitivity to changes in load. So, the system's ability to regulate voltage at the Point of Common Coupling (PCC) to the electrical system is a key factor for the successful operation of the WF. Also, is well known that given the random nature of wind resources, the wind farm generates fluctuating electric power. These fluctuations have a negative impact on stability and power quality in electric power systems. Moreover, in exploitation of wind resources, turbines employing squirrel cage induction generators (SCIG) have been used since the beginnings.

The operation of SCIG demands reactive power, usually provided from the mains and/or by local generation in capacitor banks. In the event that changes occur in its mechanical speed, i.e due to wind disturbances, so will the WF active (reactive) power injected (demanded) into the power grid, leading to variations of WF terminal voltage because of system impedance. These power disturbances propagate into the power system, and can produce a phenomenon known as "flicker", which consists of fluctuations in the illumination level caused by voltage variations. Also, the normal operation of WF is impaired due to such disturbances.

In particular for the case of "weak grids", the impact is even greater. In order to reduce the voltage fluctuations that may cause "flicker", and improve WF terminal voltage regulation, several solutions have been posed. The most common one is to upgrade the power grid, increasing the short circuit power level at the point of common coupling PCC, thus reducing the impact of power fluctuations and voltage regulation problems.

In recent years, the technological development of high power electronics devices has led to implementation of electronic equipment suited for electric power systems, with fast response compared to the line frequency. These active compensators allow great flexibility in

a) Controlling the power flow in transmission systems using Flexible AC Transmission System (FACTS) devices, and
b) Enhancing the power quality in distribution systems employing Custom Power System CUPS) devices.

II. WIND ENERGY

Wind turbines transform the energy in the wind into mechanical power, which can be used directly for grinding etc, or further converting into electric power to generate electricity. The conventional ways of generating electricity using non-renewable resources such as coal, natural gas, oil and so on, have great impacts on the environment as it contributes vast quantities of carbon dioxide to the earth's atmosphere which in turn will cause the temperature of the earth's surface to increase, known as the greenhouse effect. Hence, with the advances in science and technology, ways of generating electricity using renewable energy resources such as the wind are developed. Nowadays, the cost of wind power that is connected to the grid is as cheap as the cost of generating electricity using coal and oil. There are two types of wind turbine in relation to their rotor settings. They are:

- Horizontal-axis rotors and
- Vertical-axis rotors.

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The horizontal-axis wind turbine is designed so that the blades rotate in front of the tower with respect to the wind direction i.e. the axis of rotation are parallel to the wind direction. These are generally referred to as upwind rotors.

III. FLEXIBLE AC TRANSMISSION SYSTEMS (FACTS)

Basically the FACTS controllers are four types
1. Series controllers
2. Shunt controllers
3. Combined Series - Series controllers
4. Combined Series - Shunt controllers

A. Custom Power Devices

The classification of custom power devices can be done into two major categories, one is network configuring type and other is compensating type. The compensating devices are DSTATCOM (Distribution Static Compensator), DVR (Dynamic Voltage Restorer) and UPQC (Unified Power Quality Conditioner.

IV. UNIFIED POWER QUALITY CONDITIONER

The Unified Power quality Conditioner is a custom power device i.e employed in the distribution system to mitigate the disturbances that affect the performance of sensitive and/or critical load.
Figure

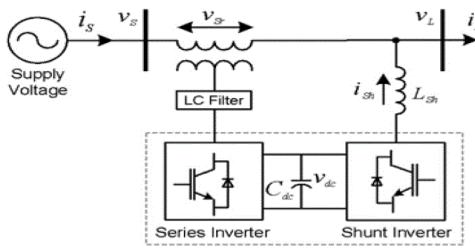

Fig1. Block Diagram of UPQC

A. Components of UPQC

The components are series and shunt inverters, D.C capacitors, low pass and high pass passive filters and series and shunt transformers.

V. SYSTEM DISCRIPTION AND MODELLING

In the model of power system WF is composed by 36 wind turbines using squirrel cage induction generators, adding up to 21.6MW electric power. Each turbine has attached fixed reactive compensation capacitor banks (175kVAr), and is connected to the power grid via 630KVA 0.69/33kV transformer. The ratio between short circuit power and rated WF power give us an idea of the "connection weakness". Thus considering that the value of short circuit power in MV6 is SSC ≃ 120MV A this ratio can be calculated:

$$r = \frac{S_{SC}}{P_{WF}} \cong 5.5$$

Values of r<20 are considered as "weak grid" connection.

The system is modelled by Turbine rotor, Induction Generator and Dynamic compensator.

A. Turbine Rotor and Associated Disturbances Model

The power that can be extracted from a wind turbine is determined by the following expression.

$$P = \frac{1}{2}\rho \pi R^2 v^3 C_p$$

where ρ is air density, R the radius of the swept area, v the wind speed, and C_P is the power coefficient.

For the considered turbines (600kW) the values are R = 31.2 m, ρ = 1.225 kg/m3 and C_P calculations are taken. Then, a complete model of the WF is obtained by turbine aggregation; this implies that the whole WF can be modelled by only one equivalent wind turbine, whose power is the arithmetic sum of the power generated by each turbine according to the following equation:

$$P_T = \sum_{i=1\ldots36} P_i$$

Moreover, wind speed 'v' can vary around its average value due to disturbances in the wind flow. Such disturbances can be classified as deterministic and random. The firsts are caused by the asymmetry in the wind flow "seen" by the turbine blades due to "tower shadow" and/or due to the atmospheric boundary layer, while the latter are random changes known as "turbulence". For our analysis, wind flow disturbance due to support structure (tower) is considered, and modelled by a sinusoidal modulation superimposed to the mean value of v.

B. Dynamic Compensator Model

The dynamic compensation of voltage variations is performed by injecting voltage in series and active–reactive power in the MV6 (PCC) bus bar; this is accomplished by using a unified type compensator UPQC. 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 of series and shunt sharing the same DC–bus, which enables the active power exchange between them.

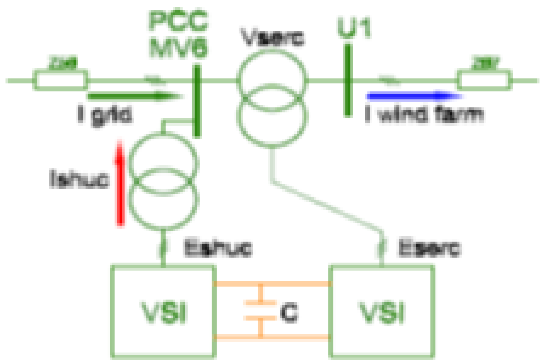

Fig 1 Block Diagram of UPQC

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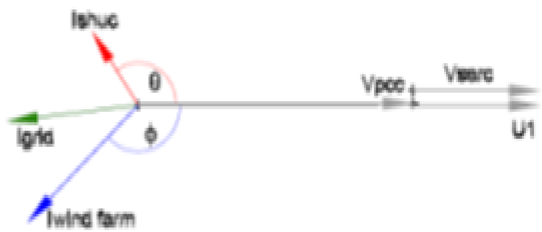

Fig2. Phasor Diagram of UPQC

C. UPQC Control Strategy

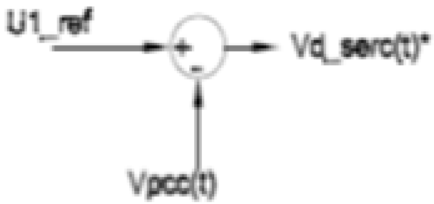

Fig 3. Series Compensator Controller

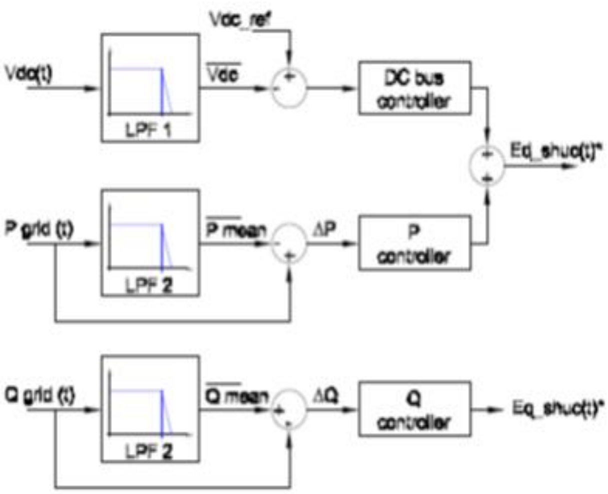

Fig 4 Shunt Compensator Controller

VI. SIMULATION RESULTS OF WINDFARM TO WEAK-GRID CONNECTION

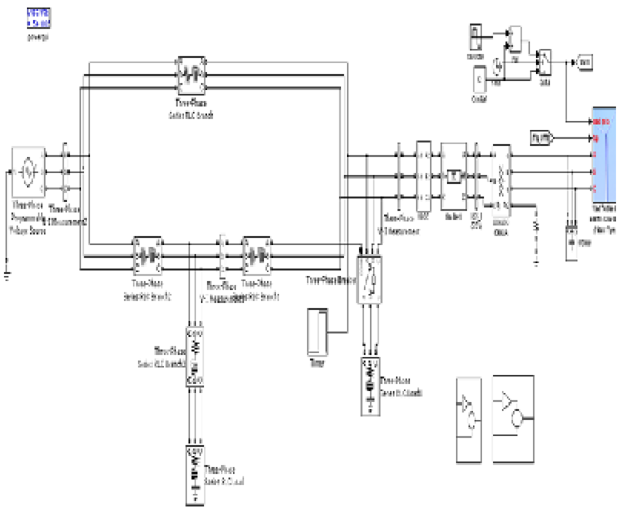

Fig 1 Main Circuit Model

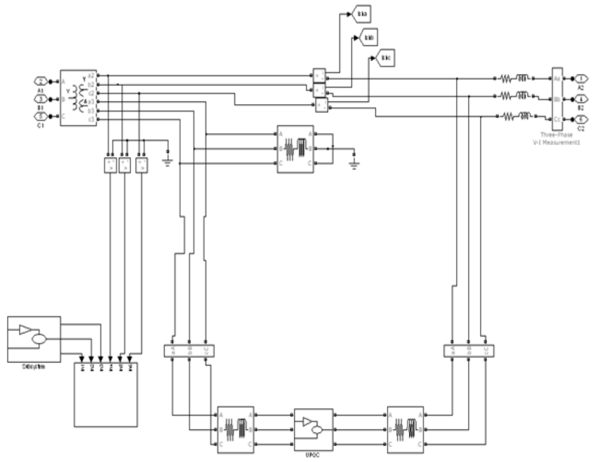

Fig 2. UPQC Sub-system

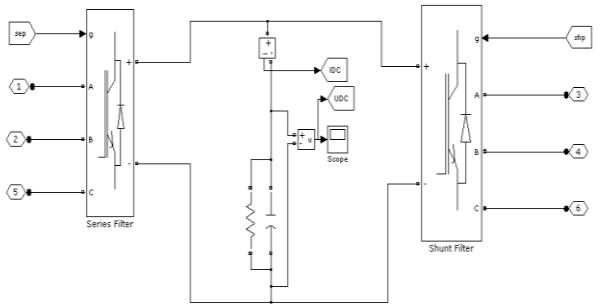

Fig. 3 UPQC Sub-system Sub-block

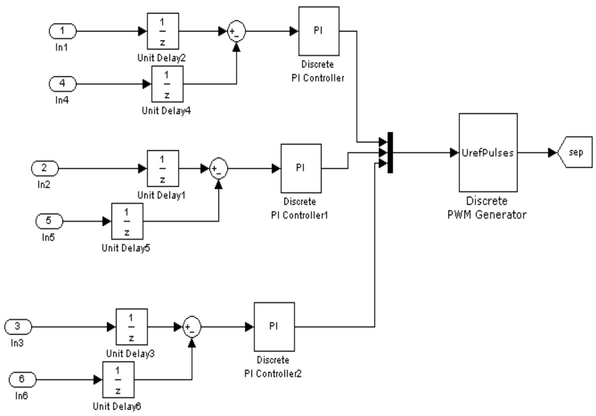

Fig . 4 Series Controller Compensation

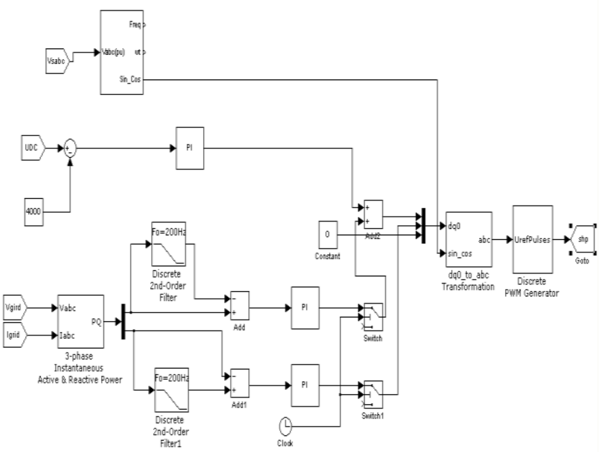

Fig. 5 Shunt Compensator Compensation

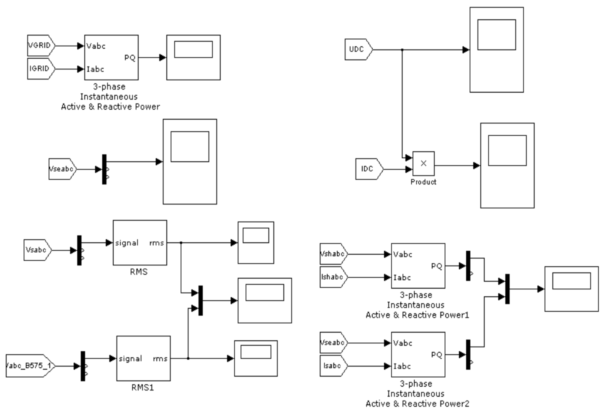

Fig. 6 Power System Model

Numerical simulations were performed to determine and then compensate voltage fluctuation due to wind power variation, and voltage regulation problems due to a sudden load connection.

The simulation was conducted with the following chronology:
• At t = 0.0″ the simulation starts with the series converter and the DC–bus voltage controllers in operation.
• At t = 0.5″ the tower shadow effect starts
• At t = 3.0″ Q and P control loops are enabled
• At t = 6.0″ L3 load is connected.
• At t = 10.0″ L3 load is disconnected.

A. Simulation Results

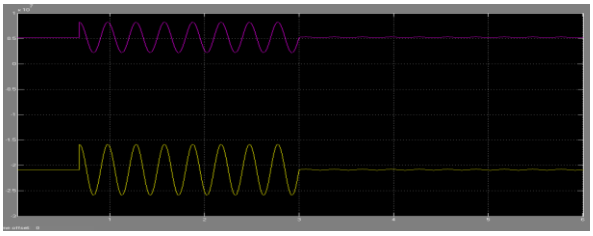

Fig. 1 Simulation result of Active and reactive power demand at power grid side.

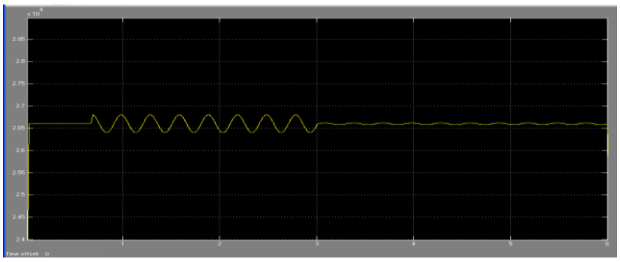

Fig. 2 Simulation result of PCC voltage.

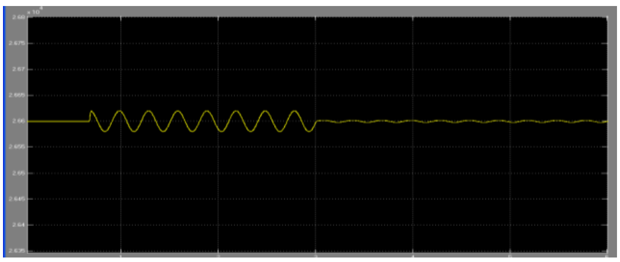

Fig. 3 Simulation result of WF terminal voltages.

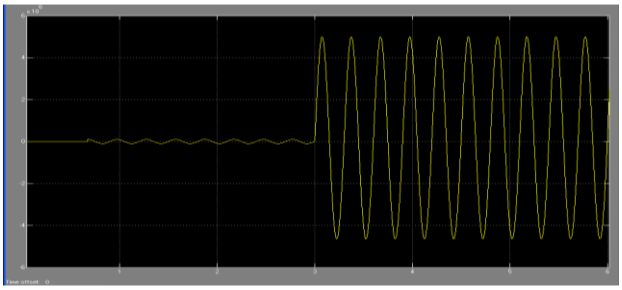

Fig. 4 Simulation result of Power in the D.C–Bus

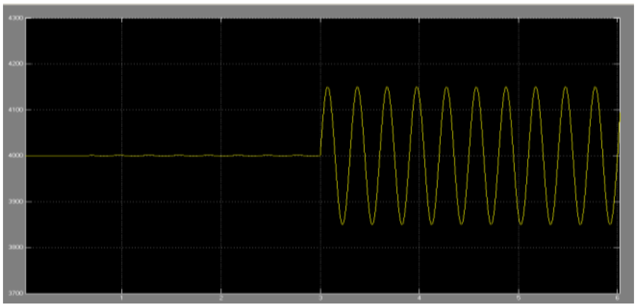

Fig. 5 Simulation result of Voltage of the capacitor in the D.C–Bus

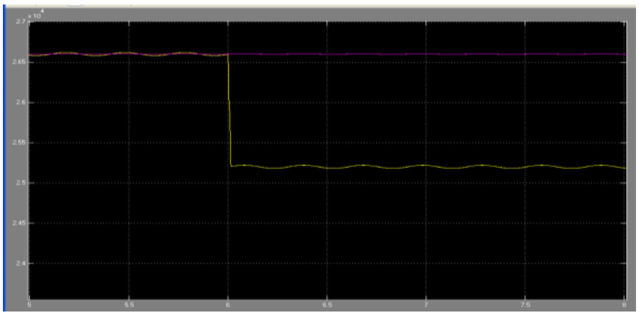

Fig. 6 Simulation result of Voltage at WF, at PCC

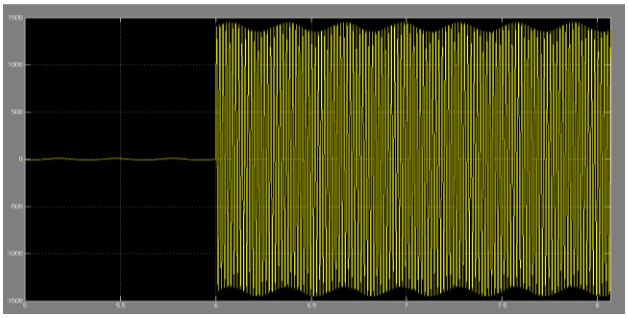

Fig. 7 Simulation result of Series injected voltage at "a" phase

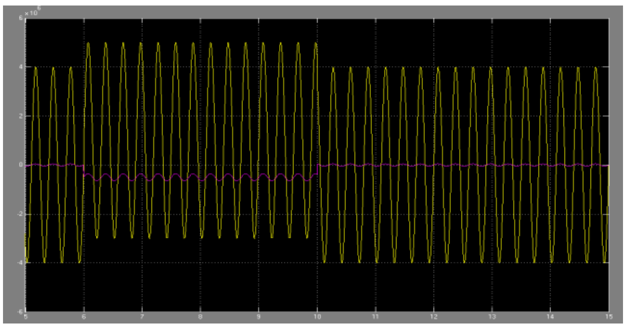

Fig. 8 Simulation result of Shunt and series converter active–power:

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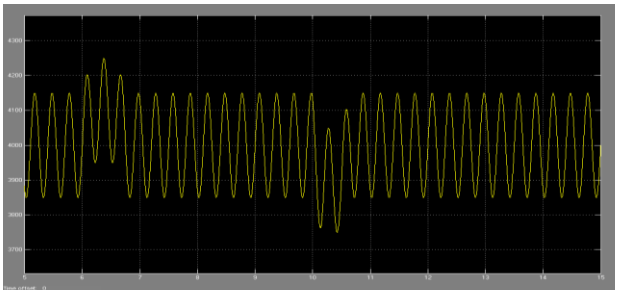

Fig. 9 DC–bus voltage, and is clearly seen the VDC control action.

VII. CONCLUSION

In order to protect critical loads from more voltage harmonics and current harmonics in the distribution network, the UPQC i.e, series connected voltage-source converter known as Dynamic Voltage Restorer and shunt connected voltage source convertor known as DSTATCOM is suitable and satisfactory.

The MATLAB/SIMULINK were used to carryout extensive simulation studies on unified power quality conditioner and for controlling purpose the proportional integral controller is used and adjustable speed drive is used as load. Therefore, UPQC is considered to be an efficient solution. Unified Power Quality Conditioner is capable of reducing the level of THD in the case of networks which are connected to the harmonics generating load. All type of faults are also compensated using UPQC.

A. Scope for Future Work

The above work can be extended in the following related areas

- The load in the system can be replaced by some other load example turbine load and electric furnace.
- The more advanced controllers such as controller, artificial neural network and instantaneous power theory can also be used with UPQC to make the system more effective.
- Effectiveness of multilevel UPQC can be investigated.

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