ISSN : 2248-9622, Vol. 3, Issue 5, Sep-Oct 2013, pp.1333-1337

RESEARCH ARTICLE OPEN ACCESS

Control of Power at Weak-Grid Using Upqc

Bhanu Ganesh Lukka, Bongu Mahesh, Vutukoori Bharath

Abstract
In this paper a compensation strategy based on a particular CUPS device, the Unified Power Quality Compensator (UPQC) has been proposed. A customized internal control scheme of the UPQC device was developed to regulate the voltage in the WF terminals, and to mitigate voltage fluctuations at grid side. The voltage regulation at WF terminal is conducted using the UPQC series converter, by voltage injection "in phase" with PCC voltage. On the other hand, the shunt converter is used to filter the WF generated power to prevent voltage fluctuations, requiring active and reactive power handling capability. The sharing of active power between converters, is managed through the common DC link. Therefore 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.
Indexterms: windfarm, weakgrid, upqc, induction generator, cups.

I. 1.Introduction

The term 'weak grid' is used in many connections both with and without the inclusion of wind energy. It is used without any rigour definition usually just taken to mean the voltage level is not as constant as in a 'stiff grid'. Put this way the definition of a weak grid is a grid where it is necessary to take voltage level and fluctuations into account because there is a probability that the values might exceed the requirements in the standards when load and production cases are considered.

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 centers [1]. In case of facilities with medium power ratings, the WF is connected through medium voltage (MV) distribution headlines. A situation commonly found in such scheme is that the power generated is comparable to the transport power capacity of the power grid to which the WF is connected, also known as weak grid connection. The main feature of this type of connections, is the increased voltage regulation sensitivity to changes in load [2]. 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 WF generates fluctuating electric power.These fluctuations have a negative impact on stability and power quality in electric power systems. [3] 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 [4], [5]. In the event that changes occur in its mechanical speed, ie 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. This 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 [5].

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 [6].

II. System description

The relationship between the power produced by the wind source and the velocity of the wind and the rotor blades swept diameter is shown below.

$$P_{wind} = \frac{\pi}{8} dD^2 v_{wind}^3 \quad (1)$$

The derivation to this formula can be looked up in [2]. It should be noted that some books derived the formula in terms of the swept area of the rotor blades (A) and the air density is denoted as δ.

In order to analyze the behavior of an induction generator, the operation of an Induction motor must be fully understood. Once, the equivalent circuit parameters have been obtained, the performance of an induction motor is easy to determine. As shown in Fig, the total power Pg transferred across the air gap from the stator is

$$P_{ag} = I_r^2 \frac{R_r}{s} \tag{2}$$

And it is evident from figure 3 that the total rotor loss Prloss is

$$P_{rloss} = I_r^2 R_r \tag{3}$$

Therefore, the internal mechanical power developed by the motor is

$$P_d = P_{ag} - P_{rloss} = I_r^2 \frac{R_r}{s} - I_r^2 R_r = I_r^2 R_r \left(\frac{1}{s} - 1\right) = I_r^2 R_r \left(\frac{1-s}{s}\right) \tag{4}$$

From the power point , where the mechanical power per stator phase is equal to the power absorbed by the resistance R2(1-s)/s.

Where,

$$P_{ag} = P_{in} - P_{Scu} - P_{core}$$

$$P_d = P_{ag} - P_{core}$$

$$P_{out} = P_{shaft} = P_d - P_{rot}$$

The parameters of an induction generator can be determined by using the no-load test and block rotor test (The steps in calculating the parameters and the test results obtained from a 440V, 2.2kW induction motor) .

III. UPQC

3.1.Operation of UPQC

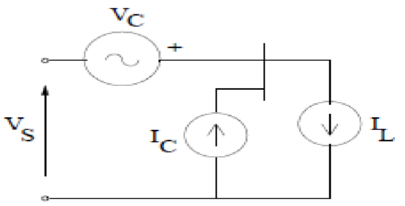

Fig.1.Basic operation of UPQC.

The operation of a UPQC can be explained from the analysis of the idealized equivalent circuit shown in Fig.1. Here, the series converter is represented by a voltage source VC and the shunt converter is represented by a current source IC. Note that all the currents and voltages are 3 dimensional vectors with phase coordinates. Unlike in the case of a UPFC, the voltages and currents may contain negative and zero sequence components in addition to harmonics. Neglecting losses in the converters, we get the relation

$$\langle V_L, I_C \rangle + \langle V_C, I_S \rangle = 0 \tag{5}$$

Where X,Ydenote the inner product of two vectors, defined by

$$\langle X, Y \rangle = \frac{1}{T} \int_0^T X^t(\tau) Y(\tau) d\tau.$$

Let the load current IL and the source voltage VS be decomposed into two
Components given by

$$I_L = I_L^{1p} + I_L^r$$

$$V_S = V_S^{1p} + V_S^r$$

Where I1p L contains only positive sequence, fundamental frequency components Similar comments apply to V 1pS. IrL and V rS contain rest of the load current and the source voltage including harmonics. I1pL is not unique and depends on the power factor at the load bus. However, the following relation applies for I1p L .

$$P_L = \langle V_L, I_L \rangle = \langle V_L, I_L^{1p} \rangle$$

This implies that hIrL ; VLi = 0. Thus, the fundamental frequency, positive sequence component in IrL does not contribute to the active power in the load. To meet the control objectives, the desired load voltages and source currents must contain only positive sequence, fundamental frequency components and

$$P_L = |V_L^* I_S^*| \cos \phi_l = |V_S^{1p} I_S^*| \cos \phi_s \tag{6}$$

Where V ¤ L and I¤S are the reference quantities for the load bus voltage and the source current respectively. Ál is the power factor angle at the load bus while Ás is the power factor angle at the source bus (input port of UPQC). Note that V ¤ L(t) and I¤S (t) are sinusoidal and balanced. If the reference current (I¤C) of the shunt converter and the reference voltage (V ¤ C) of the series converter are chosen as

$$I_C^* = I_L^*, \quad V_C^* = -V_S^r + V_C^{1p}$$

IV. Control Strategies

Several different control strategies exist for a power controller with storage. The different control strategies place different weights on voltage and power fluctuations and therefore have different impact on the sizing of the storage capacity and of the power rating. The two main types of control strategies are ones controlling the voltage at the point of common connection or another point in the grid and the ones controlling the power for smoothing or capacity increase. Instead of controlling the voltage at the point of connection another control parameter could be the output power from a wind farm. The objective can e.g.

be to keep the output power as constant as possible. This will eliminate voltage fluctuations generated by the wind farm and therefore also flicker

V. SYSTEM DESCRIPTION AND MODELLING

5.1.System description

The 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. This system is taken from [7], and represents a real case. 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:

$$r = \frac{S_{SC}}{P_{WF}} \simeq 5.5 \qquad (7)$$

Values of r < 20 are considered as a "weak grid" connection [2].

5.2. Turbine rotor and associated disturbances model

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

$$P = \frac{1}{2} \cdot \rho \cdot \pi \cdot R^2 \cdot v^3 \cdot C_P \qquad (1)$$

Where _ is air density, R the radius of the swept area, v the wind speed, and CP the power coefficient. For the considered turbines (600kW) the values are R = 31.2 m CP calculation is taken from [8]. Then, a complete model of the WF is obtained by turbine aggregation; this implies that the whole WF can be modeled by only one equivalent wind turbine, whose power is the arithmetic sum of the power generated by each turbine according to the following equation:

$$P_T = \sum_{i=1\cdots 36} P_i \qquad (2)$$

Moreover, wind speed v in (1) 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 modeled by a sinusoidal modulation superimposed to the mean value of v. The frequency for this modulation is 3 ・Nrotor for the three–bladed wind turbine, while its amplitude depends on the geometry of the tower. In our case we have considered a mean wind speed of 12m/s and the amplitude modulation of 15%. The effect of the boundary layer can be neglected compared to those produced by the shadow effect of the tower in most cases [3]. It should be noted that while the arithmetic sum of perturbations occurs only when all turbines operate synchonously and in phase, this is the case that has the greatest impact on the power grid (worst case), since the power pulsation has maximum amplitude. So, turbine aggregation method is valid.

5.3.Model of induction generator

For the squirrel cage induction generator the model available in Matlab/Simulink SimPowerSystemsc libraries is used. It consists of a fourth–order state–space electrical model and a second–order mechanical model [5].

5.4. Dynamic compensator model

The dynamic compensation of voltage variations is performed by injecting voltage in series and active–reactive power in the MV6 (PCC) busbar; this is accomplished by using an unified type compensator UPQC [9]. In Fig.6 we see the basic outline of this compensator; the busbars and impedances numbering is referred to Fig.6. 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 converter are preferred because of lower DC link losses and faster response in the system than CSI [9]. The shunt converter of UPQC is responsible for injecting current at PCC, while the series converter generates voltages between PCC and U1. An important feature of this compensator is the operation of both VSI converters (series and shunt) sharing.

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

$$\begin{aligned} P_{shuC}(t) &= \tfrac{3}{2} \cdot V_d^{PCC}(t) \cdot I_d^{shuC}(t) \\ Q_{shuC}(t) &= -\tfrac{3}{2} \cdot V_d^{PCC}(t) \cdot I_q^{shuC}(t) \end{aligned} \qquad (5)$$

Ignoring PCC voltage variation, these equations can be written as follows.

$$\begin{aligned} P_{shuC}(t) &= k'_p \cdot I_{d\_shuC}(t) \\ Q_{shuC}(t) &= k'_q \cdot I_{q\_shuC}(t) \end{aligned} \qquad (6)$$

Taking in consideration that the shunt converter is based on a VSI, we need to generate adecuate voltages to obtain the currents in (6). This is achieved using the VSI model proposed sin [10].

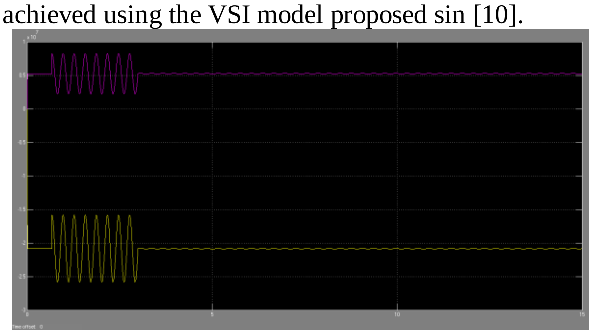

Fig.2.Active , Reactive power at grid.

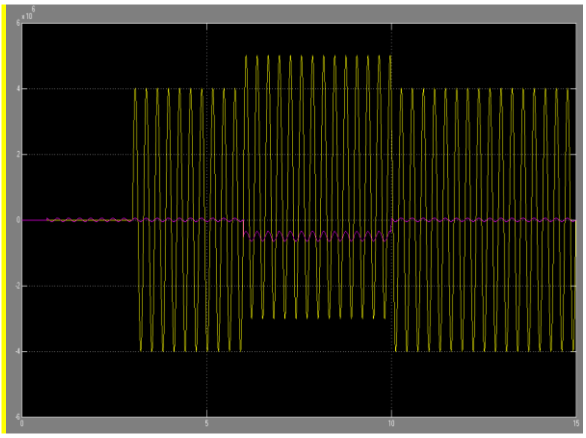

Fig.3.Active,Reactive power at Converter.

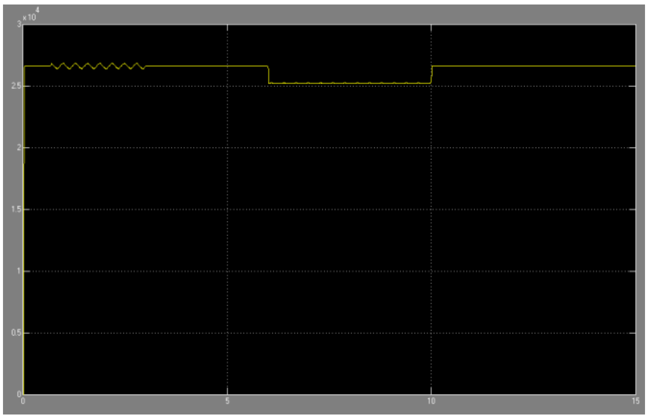

Fig.3. Voltage at shunt converter.

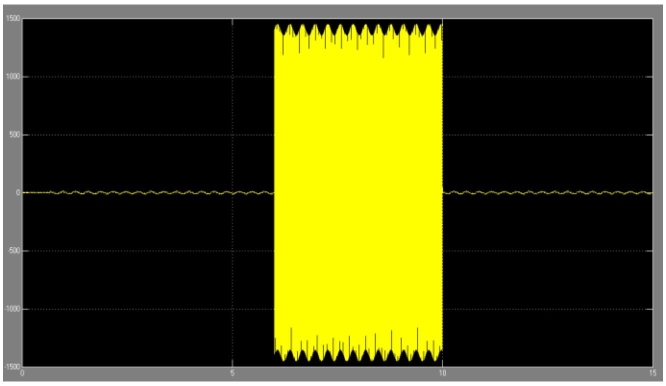

Fig.4. Voltage at Series converter.

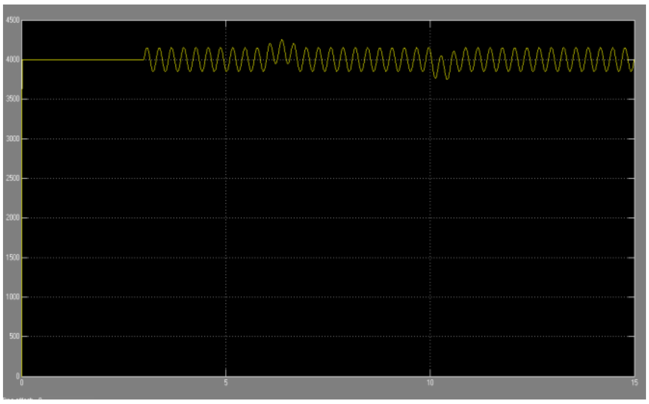

Fig.5. Voltage at DC link.

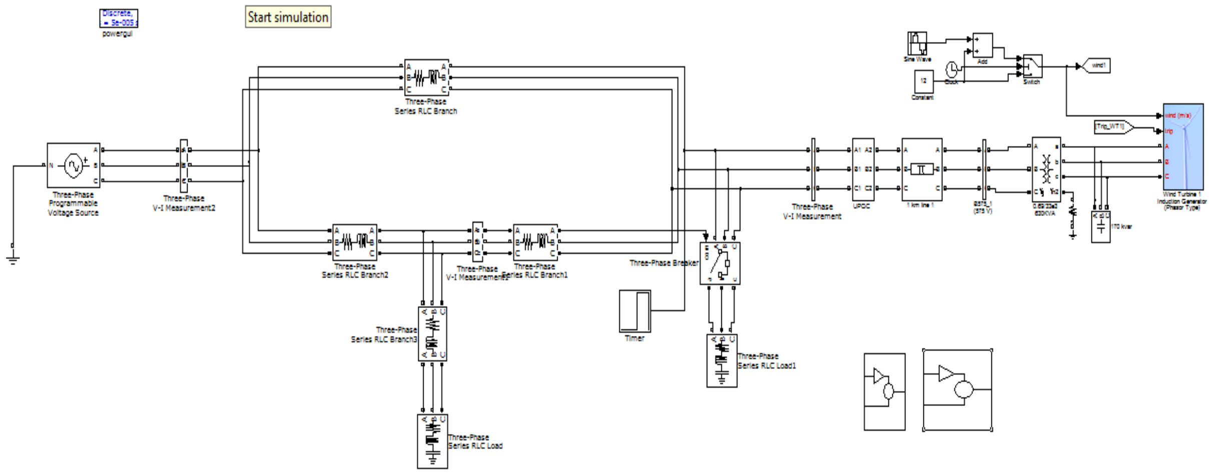

Fig.6. Simulation model of proposed circuit.

VI. CONCLUSION

In this paper, a new compensation strategy implemented using an UPQC type compensator was presented, to connect SCIG 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. The simulation results 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 study case. In future work, performance comparison between different compensator types will be made.

REFERENCES

[1] M.P. P´alsson, K. Uhlen, J.O.G. Tande. “Large-scale Wind Power Integration and Voltage Stability Limits in Regional Networks”; IEEE 2002. p.p. 762–769

[2] P. Ledesma, J. Usaola, J.L. Rodriguez "Transient stability of a fixed speed wind farm" Renewable Energy 28, 2003 pp.1341–1355
[3] P. Rosas "Dynamic influences of wind power on the power system". Technical report RISØR-1408. Ørsted Institute. March 2003.
[4] R.C. Dugan, M.F. McGranahan, S. Santoso, H.W. Beaty "Electrical Power Systems Quality" 2nd Edition McGraw–Hill, 2002. ISBN 0-07- 138622-X
[5] P. Kundur "Power System Stability and Control" McGraw-Hill, 1994. ISBN 0-07-035958-X
[6] N. G. Hingorani y L. Gyugyi. "Understanding FACTS". IEEE Press; 2000.
[7] Z. Saad-Saoud, M.L. Lisboa, J.B. Ekanayake, N. Jenkins and G. Strbac "Application of STATCOM's to wind farms" IEE Proc. Gen. Trans. Distrib. vol. 145, No. 5; Sept. 1998
[8] T. Burton, D. Sharpe, N. Jenkins, E. Bossanyi "Wind Energy Handbook" John Wiley & Sons, 2001. ISBN 0-471-48997-2.

About Authors:

Bhanu Ganesh Lukka
He received M.Tech(PEPS) degree from KL University in 2011, and B.Tech(EEE) degree from Acharya nagarjuna university in 2008, now he is working as Asst.prof in vignan college of engineering and technology, Hyderabad.

Bongu Mahesh
He received B.Tech(EEE) degree from AITS ,Hyderabad in 2011. Now he pursuing his M.Tech(PE&ED) degree in Vignan Institute of Technology and Sciences, Hyderabad .

Vutukoori Bharath
He received B.Tech (EEE) degree from Nagarjuna Institute of Technology and Scinces ,miryalaguda, now he pursuing his M.Tech (PE&ED) degree from Vignan Institute of Technology and Sciences**.**