International Journal of Power Electronics and Drive System (IJPEDS)
Vol. 5, No. 4, April 2015, pp. 477~485
ISSN: 2088-8694

Power Quality Improvement Using Custom Power Devices in Squirrel Cage Induction Generator Wind Farm to Weak-Grid Connection by using Neuro-fuzzy Control

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Article Info

Article history:

Received Jun 12, 2014
Revised Nov 18, 2014
Accepted Dec 5, 2014

Keyword:

DClink
Neuro-fuzzy logic control
Simulation
SCIG
UPQC

ABSTRACT

Wind farm is connected to the grid directly.The wind is not constant voltage fluctuations occur at point of common coupling (PCC) and WF terminal. To overcome this problem a new compensation strategy is used. By using Custom power devices (UPQC).It injects reactive power at PCC. The advantages of UPQC are it consists of both DVR and D-STATCOM. DVR is connected in series to the line and it injects in phase voltage into the line .D-STATCOM is connected shunt to the line .The internal control strategy is based on management of active and reactive power in series and shunt converters of UPQC. The power exchainge is done by using DC-link.

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1. INTRODUCTION

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. In case of facilities with medium power ratings, the Wind Farm is connected through medium voltage (MV) distribution headlines.

Also, is well known that given the random nature of wind resources, the wind farm generates fluctuating electric power. These oscillations have a negative impact on stability and power quality in electric power systems. furthermore, in development of wind resources, turbines utilizing squirrel cage induction generators (SCIG) have been used since the beginnings. The operation of squirrel cage induction generator demands reactive power, generally provided from the mains and/or by local generation in capacitor banks [1].

In the event that changes occur in its mechanical speed, i.e. due to wind disturbances will the WIND FARM active (reactive) power injected (demanded) into the power grid, leading to variations of wind farm Terminal voltage because of system impedance. This power disturbances transmit 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 Wind Farm is impaired due to such disturbances. In particular for the case of "weak grids", the impact is even better.

In order to reduce the voltage fluctuations that may cause "flicker", and improve Wind Farm terminal voltage regulation, several results have been posed. The most common one is to raise the power grid, enhancing the short circuit power level at the point of common coupling point of common coupling, 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 very fast response compared to the line frequency. These active compensators allow groovy flexibility in: I) controlling the power flow in transmission systems using Flexible AC Transmission System (FACTS) devices, and II) enhancing the power quality in distribution systems employing Custom Power System (CUPS) devices [2]. The use of these active compensators to improve integration of wind energy in weak grids is the approach adopted in this work. In this project we analyse a compensation strategy using an UPQC, for the SCIG–based Wind Farm connected to a weak distribution power grid. This system is taken from a real case [3].

The UPQC is controlled to regulate the Wind Farm terminal voltage, and to mitigate harmonics at the point of common coupling (PCC), caused by system load changes in generated power of Wind Farm, respectively. By using UPQC series converter in wind farm voltage regulation process was done, by voltage injection "in phase" with PCC voltage.

The shunt converter is used to filter the Wind Farm generated power to forbid voltage flickers in active and reactive power capability. The sharing of active power between converters, is supervised through the common DC link.

2. SYSTEM DESCRIPTION AND MODELLING

2.1. System Description

Figure 1 depicts the power system under consideration in this study.

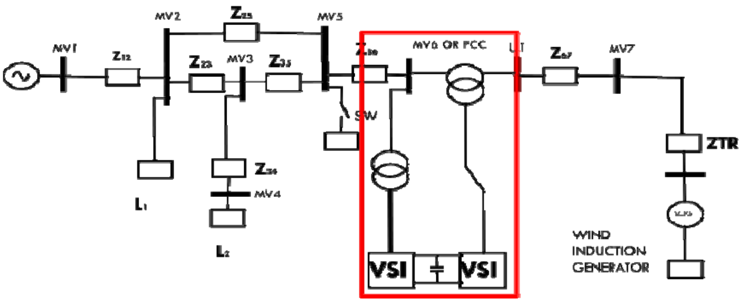

Figure 1. Single line diagram of wind farm connected to week grid system

The Wind Farm is composed by 36 wind turbines using SCIG, adding up to 21.6MW electric power. Each turbine has given fixed reactive compensation capacitor banks (175kVAr), and is connected to the power grid via 630KVA 0.69/33kV transformer. This system is Carry out from, and represents a real case.

The ratio between short circuit power and rated WIND FARM 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:

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

Values of r < 19 are considered as a "weak grid" connection [2].

2.2. Turbine Rotor and Associated Disturbances Model

The power that can be obtained from a wind turbine, is expressed by:

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

Where: ρ is air density

R the radius of the swept area

v the wind speed

CP the power coefficient

For the assumed turbines (600kW) the values are R = 31.2 m , ρ = 1.225 kg/m3 and CP calculation is taken from [4].

A complete model of the wind farm is obtained by turbine aggregation; this means that the whole wind farm can be modelled by only a equivalent wind turbine, whose power generated by the arithmetic sum of each turbine according to the equation given below:

$$P_T = \sum_{i=1.........36} P_i$$

Wind speed v in eqn (1) can differ around its average value due to variation in the wind flow. Such variations can be classified as random and deterministic. The first are caused by the symmetry in the wind flow observed by the turbine blades due to tower shadow and due to the atmospheric boundary layer, while the latter are random changes known as turbulence. For our analysis, wind flow variation due to support structure is considered, and modeled by a sinusoidal modulation superimposed to the mean value of v. The frequency for this modulation is $3.N_{rotor}$ for the three bladed wind turbine, while its distance 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 ignored compared to those produced by the shadow effect of the tower in almost cases [3]. It should be noted that while the arithmetic sum of perturbations occurs when all turbines function synchronously and in phase, this is the case that has the great impact on the power grid, since the power pulsation has high amplitude. So, turbine aggregation method is valid.

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3. MODEL OF INDUCTION GENERATOR

The model available in Matlab/Simulink Sim Power Systems library the squirrel cage induction generator is used. It consists of a second–order mechanical model and a fourth–order state–space electrical model [5].

4. DYNAMIC COMPENSATOR MODEL

The dynamic compensation of voltage changes is performed by injecting voltage in series and active & reactive power into the MV6 (PCC) busbar; this is accomplished by using an UPQC [1]. In Figure 2 we can see the basic single line diagram of this compensator; the impedances and busbars numbering is referred to Figure 1.

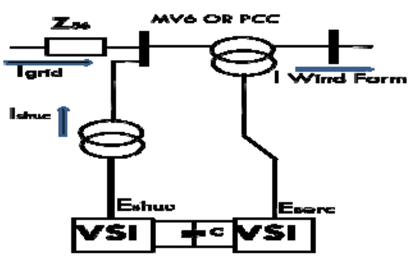

Figure 2(a). Block diagram of UPQC

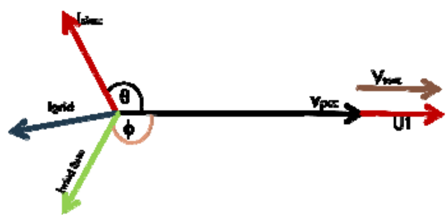

Figure 2(b). Phasor diagram of UPQC

The operation is based on the generation of three phase voltages, using power electronic converters either current source type Current Source Inverter or voltage source type Voltage Source Inverter. Voltage Source converters are preferred. Faster response in the system than CSI [1] and It has lower DC link losses. The shunt converter of UPQC injecting current at PCC, hear the series converter generates voltages between U1 and PCC, illustrated in the phasor diagram of Figure 3. An important feature of this compensator is the operation of both VSI converters sharing the same DC–bus, it enables the active power exchange between them.

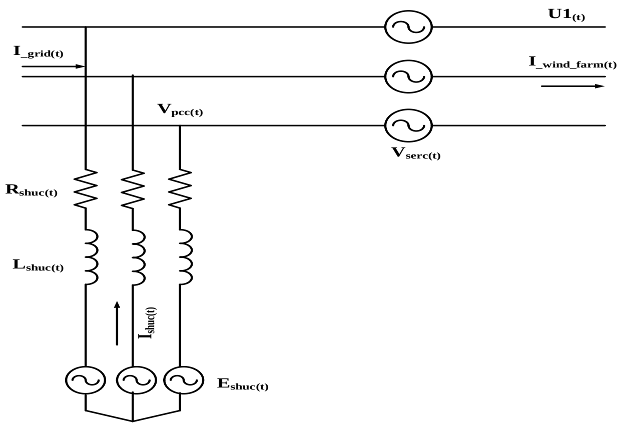

Figure 3. Power stage compensation model AC side

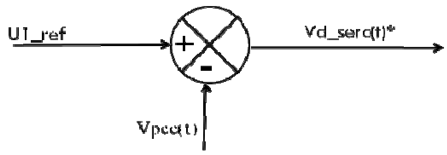

Figure 4. Series compensator controller

We have build up a simulation model for the UPQC based on the ideas chosen from [6]. Since switching control of converters is complete different of this work, and considering that higher order harmonics generated by VSI converters are outside the bandwidth of significance in the simulation study, the converters are modelled using ideal controlled voltage sources. Figure 4 shows the adopted model of power side of UPQC.

The control of the UPQC, will be enforced in a rotating frame dq0 using Park's transformation as given in Equation (3&4).

$$T = \frac{2}{3}\begin{bmatrix} \sin(\theta) & \sin(\theta - \frac{2\pi}{3}) & \sin(\theta + \frac{2\pi}{3}) \\ \cos(\theta) & \cos(\theta - \frac{2\pi}{3}) & \cos(\theta + \frac{2\pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}$$

$$\begin{bmatrix} f_d \\ f_q \\ f_0 \end{bmatrix} = T.\begin{bmatrix} f_a \\ f_b \\ f_c \end{bmatrix}$$

Where: $f_i = a, b, c$ represents phase voltage or currents

$f_i = d, q, 0$ represents magnitudes transformed to the dqo space.

This transformation admits the alignment of a rotating reference frame with the positive sequence of the PCC voltages space vector. To attain this, a reference angle_synchronized with the PCC positive sequence fundamental voltage space vector is calculated using a Phase Locked Loop (PLL) system. In this work, an "instantaneous power theory" based PLL has been enforced [7].

Under balance steady-state conditions, voltage and currents vectors in this synchronous reference frame are constant quantities. This strategy is useful for analysis and decoupled control.

5. UPQC CONTROL STRATEGY

In this paper we have used the neuro – fuzzy logic controlling strategy which is very advanced strategy now a days.

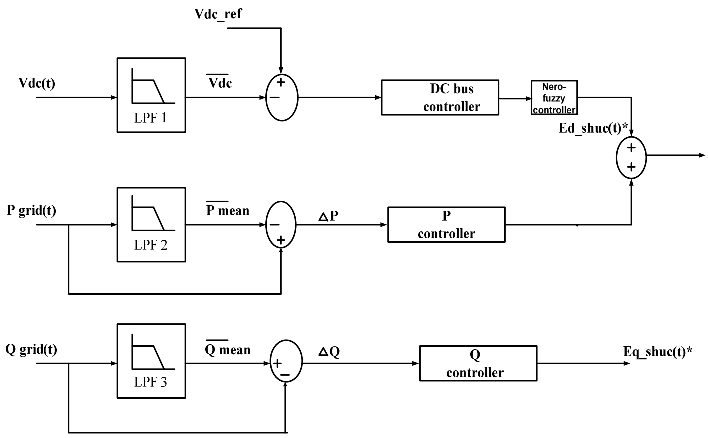

Figure 5. Shunt compensator controller using neuro – fuzzy

The powers P_{shuc} and Q_{shuc} are calculated in the rotating reference frame, as follow:

$$P_{shuc}(t) = \frac{3}{2}.V_d^{pcc}(t).I_d^{shuc}(t)$$

$$Q_{shuc}(t) = -\frac{3}{2}.V_d^{pcc}(t).I_q^{shuc}(t)$$

We Ignore PCC voltage variation, the above equations can be written as follows:

.

$$P_{shuc}(t) = k_p^{'}.I_{d\_shuc}(t)$$

$$Q_{shuc}(t) = k_q^{'}.I_{q\_shuc}(t)$$

Taking in consideration that the shunt converter is based on a VSI, we need to generate adecuate voltages to obtain the currents in equation. This is attained using the VSI model proposed in [6], leading to a linear relationship between the controller voltages and generated power. The resultant equations are:

$$P_{shuc}(t) = k_p^{"}.E^{*}{}_{d\_shuc}(t)$$

$$Q_{shuc}(t) = k_q^{"}.E_{q\_shuc}^{*}(t)$$

P and Q control loops comprise a PI controller, while DC–bus loop hear we use a neuro – fuzzy controller, In generally, in the proposed scheme the UPQC can be seen as a *power buffer*, leveling the power injected into the power system grid. The Figure 7 illustrates a conceptual diagram of this mode of operation.

It must be observed 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 scheme cannot be implemented using other CUPS devices like DVR or D–Statcom. The power buffer concept may be implemented using a DStatcom, but not using a DVR. On the other side, voltage regulation during relatively large disturbances, cannot be easily using reactive power only from DStatcom; in this work, a DVR device is more suitable.

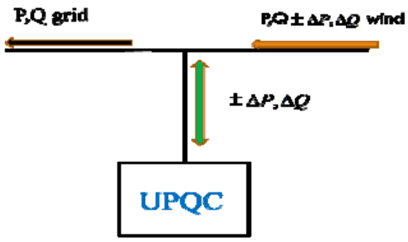

Figure 6. Power buffer concept

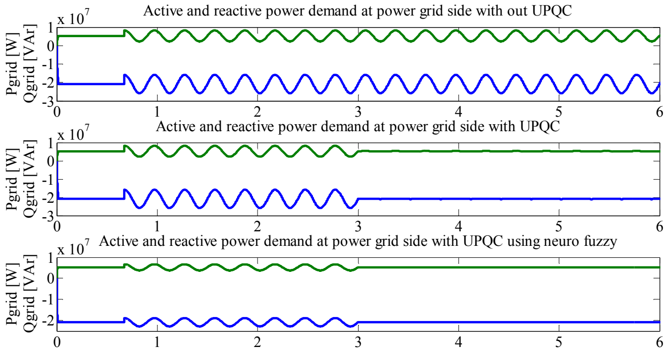

Figure 7. Active and reactive power demand at power grid

The model of the power system strategy illustrated in Figure 1, including the controllers with the control scheme detailed in section III, was implemented using Matlab/Simulink ® software. 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.

a) At t = 0.0’’ the simulation starts with the series converter and the DC-bus voltage controllers in operation.
b) At t = 0.5’’ the tower shadow effect starts
c) At t = 3.0” Q and P control loops
d) At t = 6.0” L3 load is connected.
e) At t = 6.0 “ L3 load is disconnected[8].

6. COMPENSATION OF VOLTAGE FLUCTUATION

Simulation results for 0 < t < 6 are shown in Fig.8. At t = 0.5″ begins the cyclical power pulsation produced by the tower shadow effect. As was mentioned, the tower shadow produces variation in torque, and hence in the active and reactive wind farm generated power. For nominal wind speed condition, the power fluctuation frequency is f = 3.4Hz, and the amplitude of the resulting voltage variation at PCC, expressed as a percentage is:

$$\frac{\Delta U}{U_{rated}} = 1.50\%$$

7. RESULTS AND ANALYSIS

Figure 8 is the pcc voltage is behaviour is shown the upper curve shows the voltage at pcc when UPQC is not existing. The middle curve shows the when the UPQC is connected to the grid by using PI controller. The last curve in Figure 8 shows when UPQC is connected to the grid and hear we are using neuro –fuzzy logic controller. There is a variation in the wave forms.

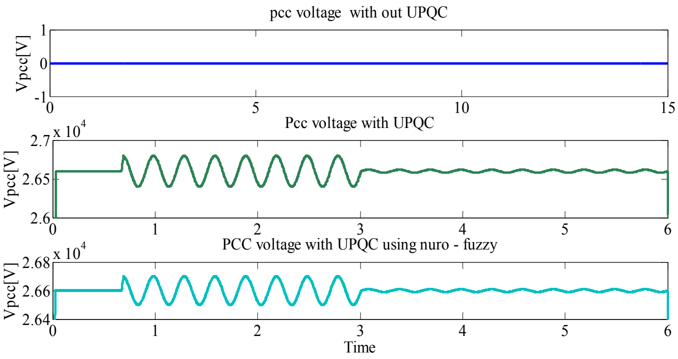

Figure 8. Pcc voltage

In the Figure 9 the shows the behaviour of wind farm terminal voltage. The upper wave form shows the behaviour when wind farm is connected to the grid when UPQC is not connected. Middle wave form is when UPQC is connected to the grid and the control strategy used is PI controller. Final wave form of Figure 9 shows the behaviour of wind farm voltage connected to the grid and the control strategy used is neuro – fuzzy logic controller.

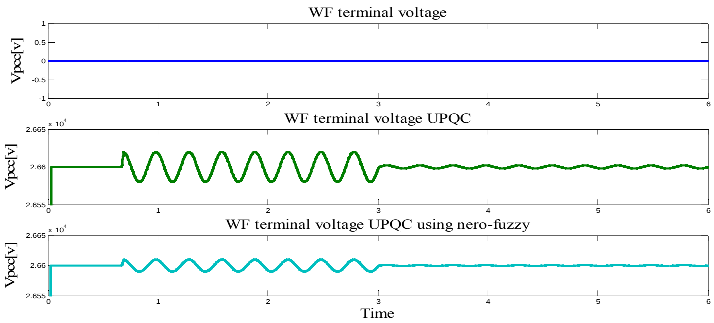

Figure 9. WF terminal voltage

This voltage fluctuation is seen in Figure 9 for $0.5 < t < 3$.

Table 1. Neuro Fuzzy Rule Base

E(K) / **ΔE**	**NB**	**NM**	**NS**	**ZE**	**PS**	**PM**	**PB**
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

In this paper the above rules are taken for [9]. In the above table PB=positive big, PM = positive medium, PS = positive small ZE = zero, NS = negative small, NM = negative medium, NB = negative big

In the Figure 10 the shows the behaviour of wind farm terminal voltage and Pcc voltage. The upper wave form shows the behaviour when wind farm is connected to the grid when UPQC is not connected.

middle wave form is when UPQC is connected to the grid and the control strategy used is PI controller. Final wave form of Figure 10 shows the behaviour of wind farm voltage connected to the grid and the control strategy used is neuro – fuzzy logic controller.

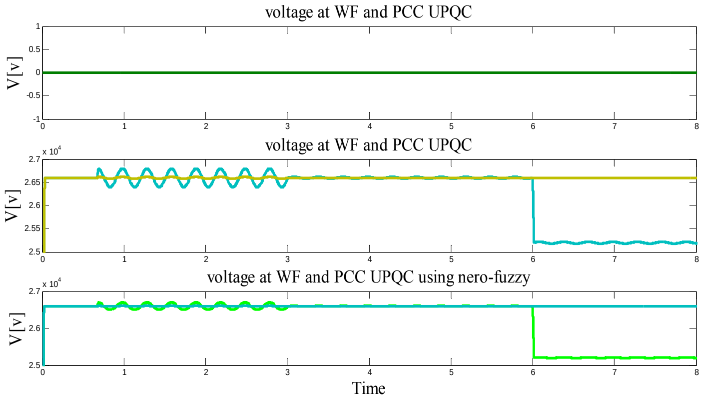

Figure 10. Voltage at Pcc and WF

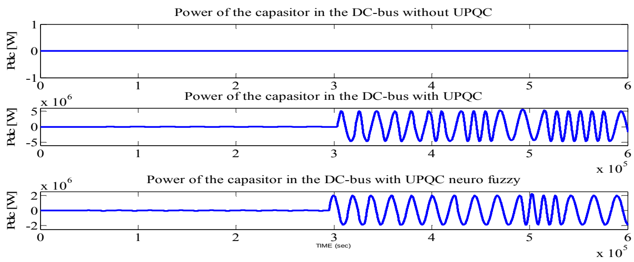

Figure 11. Power of capacitor in DC bus

The above Figure 11 is DC bus voltage at UPQC, in upper wave form there is no UPQC is connected to the grid. There is no UPQC no DC bus voltage so it is 0. The middle wave form is UPQC is connected to the grid there is variation. We have taken variation from time interval 3, so the variation starts from 3. The final wave form is also same hear we use neuro fuzzy.

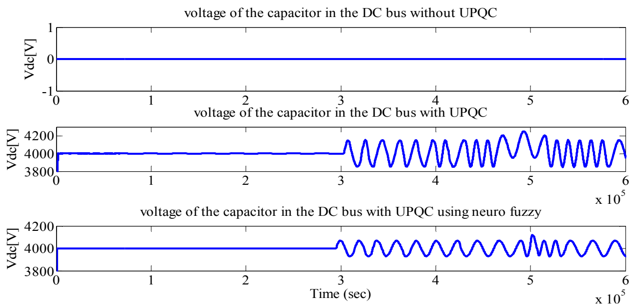

Figure 12. Voltage of the capacitor in the dc bus

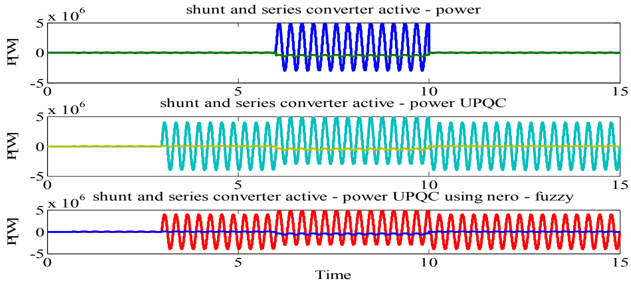

Figure 13. Shunt and series converter active power

8. CONCLUSION

In this paper, a new compensation strategy was employed using UPQC compensator. When SCIG based wind farms connected to week grid this compensation strategy is used. This compensation strategy enhances system power quality. The simulation results show the good performance in mitigating the power fluctuations due to tower shadow effect and voltage regulation in sudden load conditions.

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