Power Quality Improvement of Wind farm Connected with Grid Supply Using Intelligent Controlled UPQC

Sudhir Sharma[#1], Shivani Mehta[#2], Mukesh[*3]

[#]*Electrical Department, DAVIET*
Kabir Nagar, Jalandhar, Punjab, INDIA
[1]Sudhir.abc@gmail.com
[2]Shivanimehta7@gmail.com
[*]*M.Tech. Student Electrical Department*
DAVIET Jalandhar, INDIA
[3]Mukesh.daviet09@gmail.com

***Abstract*— The emerging advancements in the modern electrical system has increased the consumption of the electrical power to a greater extent in the recent years than the few previous years. This increase in the demand of electrical power has encouraged the generation of electrical power by other non-conventional means like solar, wind, hydro, etc. These non-conventional sources of electrical power has enormous advantages over the conventional sources of electrical power but the quality of power coming from these non-conventional sources need to be monitored because of the fact that the input supply to these non-conventional power sources is never constant and varies continuously. These variations in the input supply of the sources along with the inverters and converters used in these electrical sources leads to the distortions and harmonics in the power system which deteriorates the power quality of the system. In this paper the power quality issue of the system consisting of a wind farm connected with the Grid network is studied and discussed. An effort has been made to improve the power quality of the system up to the desired level using an intelligent controlled Unified Power Quality Conditioner (UPQC). The performance of the intelligent controlled UPQC is compared with the conventional method of controlling i.e. Proportional Integral (PI) controlled UPQC and is found to have better results and improved performance. The results are verified using MATLAB/SIMULINK software.**

***Keywords*— Unified Power Quality Conditioner (UPQC), Proportional Integral controller (PI controller), Active power filters (APF), Insulated gate bipolar transistor (IGBT), Artificial neural network (ANN), Pulse width modulation (PWM), Phase locked loop (PLL)**

I. Introduction

The electrical power is one of the most beneficial, reliable and diversified source of power used now a days in our modern era thus the demand of electrical power is increasing very steeply. This has led to the increased generation of electrical power using various conventional sources like thermal power, nuclear power, etc. at a much larger rate than the previous time in the history. This has increased the consumption of the fossil fuels and had put a burden on the reserve of nature as well as the environment is also suffering the problem of pollution. With these problems, the non-conventional and renewable resources of power came into the existence for sharing the load of the conventional resources for power generation and for rehabilitation of environment. These resources includes wind power, solar power, hydro power, etc. which are available in nature in an infinite amount and also do not pollute the environment [1]. These resources if used for electrical power generation has a lot of advantage, which includes: Low generation cost, No pollution in generation, Long life span, etc. but also there are some limitations like the amount of power generated by these resources is limited and is dependent upon the nature itself, also because of the continuously variable input supply the quality of power from these resources is not up to the mark and need to be monitored continuously. These sources of electrical power like wind power plant, solar power plant, etc. when coupled with the existing power supply network, distorts the power supply of the network itself and introduce the harmonics in it, resulting into the poor power quality of the system [2]. The power quality issue of the wind farm when connected with the electrical grid is studied and discussed in this paper and an effort has been made to improve the power quality of the system consisting of the grid supply with interconnected wind farm and a load.

The wind turbine used in this system is a 9MW variable speed pitch controlled wind turbine with a doubly-fed induction generator (DFIG) which is connected to the Grid network of 33KV to feed the 3 phase RLC load of 10e3W active power, inductive reactive power 100var positive and capacitive reactive power 100var negative at the voltage of 575V. The DFIG is the perfect for the system with large scale power wind turbines because of the fact that the inverters required to be connected to induction generators for this load will be large and expensive [3]. The DFIG consists of the two-three phase windings, one stationary and one rotating. One winding is connected directly to the grid to produce 3 phase power at desired frequency and other winding is connected to

3 phase power at variable frequency which is adjusted in frequency and phase to compensate for speed change in wind turbine. For this it contains two AC-DC converters connected back to back with a DC link in between as shown in figure 1 below. These converters are the source of distortions and harmonics in the system and results into the deterioration of the power quality of the network in which it is connected.

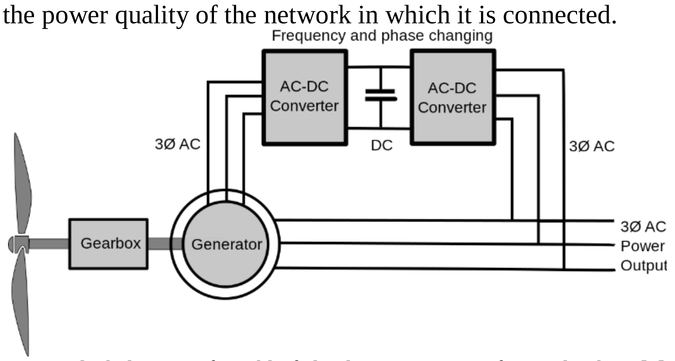

Fig. 1 Block diagram of Doubly-fed induction generator for wind turbine [3]

For the power quality improvement of the system and to remove the distortions and harmonics, a device called as Unified Power Quality Conditioner is used [4]. The power quality of the system is measured in the form of percentage THD of voltage and current waveforms at different locations in the system. The UPQC is a device which consists of two inverters connected back to back with a common DC link between them for the simultaneous compensation of current and voltage distortions and harmonics in the system in which it is connected [5]. A series injection transformer is used for injecting the series voltage into the system while shunt current is injected directly into the system. Two low pass filters are used one with each inverter for removing the high frequency switching ripples of the inverters from being injected into the system. The figure 2 explains the block diagram of the UPQC. The two inverters namely, the series and shunt inverter are controlled independently for the operation to compensate the system voltage and current respectively. The Shunt controller is also responsible for the maintaining the common DC link at the set constant voltage [6].

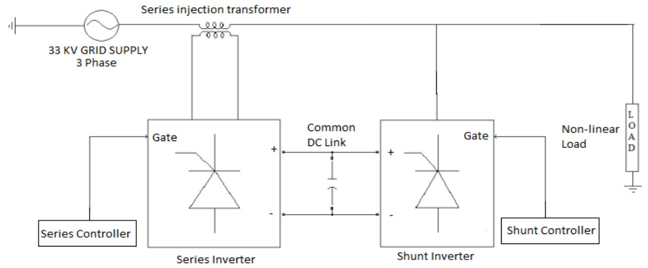

Fig. 2 Block diagram of UPQC

The basic operation of the series inverter of the UPQC can be explained using the equation given below. The series inverter injects the voltage into the circuit as determined by the equation given below [7].

$$V_{Sr}(\omega t) = V^*_S(\omega t) - V_L(\omega t) \quad (1)$$

Where $V_{Sr}(\omega t)$, $V^*_S(\omega t)$, and $V_L(\omega t)$ represent the injected series inverter voltage, reference source voltage, and the voltage of the line, respectively. The shunt inverter injects the current into the circuit as determined by the equation given below [7].

$$I_{Sh}(\omega t) = I^*_S(\omega t) - I_L(\omega t) \quad (2)$$

Where $I_{Sh}(\omega t)$, $I^*_S(\omega t)$, and $I_L(\omega t)$ represent the shunt inverter current, reference source current, and line current, respectively.

The compensation provided by the UPQC is greatly dependent upon the technique or the algorithm used for the controlling the switching of its series and shunt inverters [5]. The accurate and fast is the switching of its series and shunt inverter, the better the performance of the UPQC will be. Different controlling techniques/algorithms are available in the present literature for controlling the UPQC, among them the conventionally used controller is the Proportional Integral (PI) controller, which is simple to implement and hence widely used [5],[8]. In this paper the intelligent controller using the Artificial Neural Network is developed and used instead if PI controller for controlling the UPQC to improve the power quality of the system. The results of the power quality are compared in the terms of %THD of its voltage and current waveforms for both the conventional and intelligent controlled UPQC. The comparison of the result shows that the intelligent controlled UPQC is superior as compared to the conventional one. Section II and III of this paper discusses the Designing the conventional PI controller and intelligent controller respectively, while simulation results are presented in section IV. Section V describes the conclusion of these results.

II. DESIGNING OF PI CONTROLLER

In the series controller of the PI controlled UPQC the supply voltage is injected into the PLL, the PLL generates an angle ranging from 0 to 2π. These unit vectors are multiplied with the trigonometric functions along with the angles sinωt, sin(ωt-2π/3) and sin(ωt+2π/3). Now reference voltage is multiplied with these unit vectors to get the reference source voltage V^*_S. Then the reference voltage is compared with the line voltage V_L. Then the error is generated V_{Sr} which is being fed to the PI controller. Further the output of PI controller is given to PWM which compares the error signal with the carrier signal and hence generates the desired pulses which are being supplied to the gate of the converter. Now these pulses will trigger the series converter during the period of voltage fluctuation hence will compensate the voltage to the desired value.

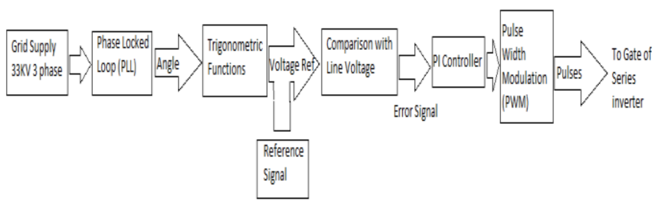

Fig. 3 Block diagram of Series control of PI controlled UPQC

The shunt controller is controlled by the theory called instantaneous reactive power theory (p-q). The reference signals which are to be supplied to the shunt converter are generated by this theory. Here the current and voltage from the source side i.e. Vsabc and Isabc are injected into the controller where p & q are generated. Further one p & q signal is passed through the low pass filter and the other through the normal line and then the signals from the filters I^*_S and normal line I_L are compared and error signal I_{Sh} is generated. This error signal I_{Sh} generated is fed into the PI controller. The p and q acts as direct and quadrature components of the signal as they are 90 degree apart. Then error signal generated by comparing V_{dc} and V_{dcref} is fed to the PI controller and then is added to the p component coming from the pq conversion block. Now d-q components are given to the multiplexer with a constant signal '0' being added with them so as to convert the signal into d-q-o signal. Now the d-q-o signal is injected in the inverse park transformation block with angle coming from PLL for synchronization and by applying inverse Park's transformation we get the signal in a-b-c frame as explained earlier in SRF theory. In PLL the phase angle was detected from the V_{sabc}. Then a-b-c components are evolved and are fed to the PWM block where it is compared with the carrier signal and relevant pulses are generated which are to be delivered to the shunt converter. Also the shunt inverter performs the important function to maintain the DC bus at the set reference value so that the desired performance can be achieved from the UPQC [6].

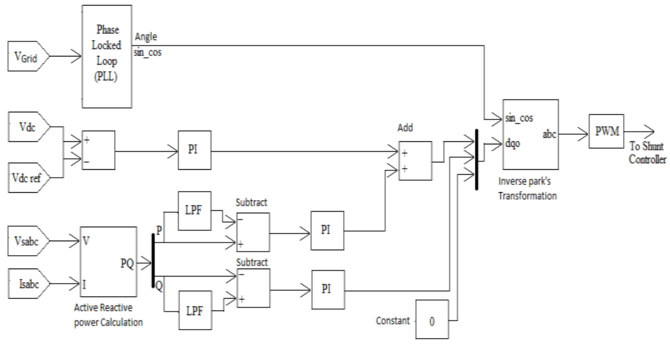

Fig. 4 Block diagram of Shunt control of PI controlled UPQC

III. DESIGNING OF INTELLIGENT CONTROLLER

In the series controller of intelligent controlled UPQC the grid supply is fed to the phase locked loop and then PLL generates an angle ranging from 0 to 2π and when the zero crossing is sensed in positive sequence phase it gets synchronized. Now unit vectors are multiplied with the trigonometric functions along with the angles sinωt, sin(ωt-2π/3) and sin(ωt+2π/3). Further the reference signal (220*sqrt2) is multiplied with these vectors to get the reference voltage. Now the reference voltage is compared with the line voltage to generate the error signal which is given to operate the relay which gives the signal to the gates of the series inverter IGBT's. The series voltage is injected through the three series transformers connected one in each phase and RL low pass filter is used in each phase to remove the high frequency switching ripples from the injected voltage [9].

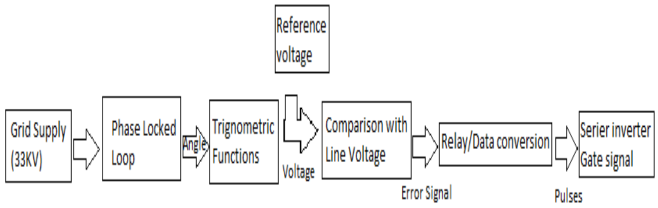

Fig. 5 Block diagram of Series control of Intelligent controlled UPQC

In the Shunt control the comparison is made between the DC bus voltage and the reference DC voltage (400V). The error signal obtained is given to the ANN. The output of the ANN Controller is added with the output of Active power estimation block via 2nd order filter and a suitable gain which is multiplies by the voltage vectors Vaalpha, Vbalpha and Vcalpha respectively and the output of which is then divided by the sum of square of voltages from (Valpha and Vbeta) to get the value of three phase reference current, these values of reference currents are then compared with line current to get the error signal which is fed to the relay and Data type conversion block to feed the gates of various IGBT's of Shunt inverter. The current compensation is injected directly to the three phase lines without any transformer [10] as shown in the figure and RL low pass filter is connected in each phase to remove the high frequency switching ripples.

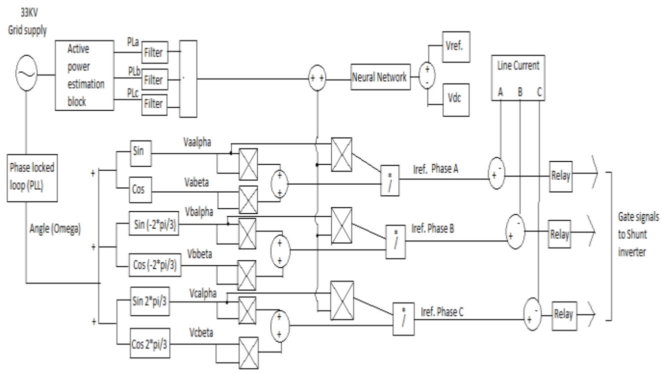

Fig. 6 Block diagram of Shunt control of intelligent controlled UPQC

The ANN consisting of the interconnected artificial neurons which have the ability to learn and adapt. These intelligent networks are characterised in the manner they are trained, their communication with the environment and the way in which they use their information and their ability to use it [11],[12]. The Neural network is made with three layers, the input layer, the second layer which is also called as hidden layer and the output layer as shown in figure below.

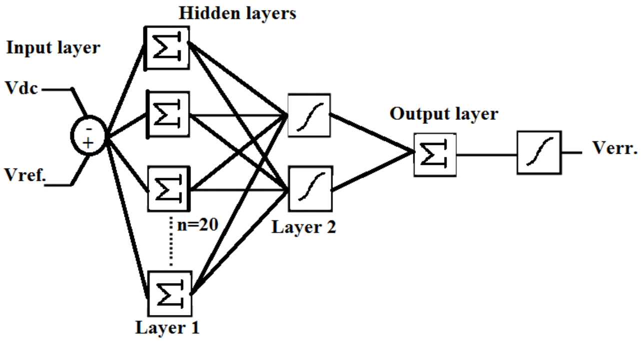

Fig. 7 Network topology for ANN

Where I_{Sh} (ωt), I^*_S (ωt), and I_L (ωt) represent the shunt inverter current, reference source current, and line current, respectively.

IV. SIMULATION RESULTS

In the MATLAB/SIMULINK model the wind turbine used is a 9MW (6*1.5MW each) variable speed pitch controlled wind turbine with a doubly-fed induction generator (DFIG) [13][14] which is connected to the Grid network of 33KV to feed the 3 phase RLC load of 10e3W active power, inductive reactive power 100var positive and capacitive reactive power 100var negative at the voltage of 575V. Percentage THD analysis is done on five different locations in the power system i.e.

1. At GRID side
2. At Point of common coupling (PCC)
3. At Transformer (T/F) side
4. At point of load connection
5. At extreme Non-linear load side

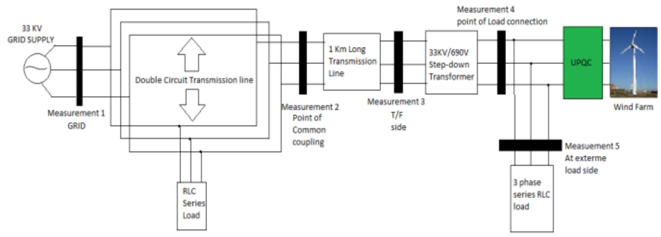

Fig 8: Block diagram of Simulation model used for THD analysis of the powers system

The results obtained from the THD analysis of the system without UPQC, with conventional UPQC and with intelligent controlled UPQC at different locations in the power system are as shown in the Table 1.

TABLE I
Comparison of %THD of Voltage and Current with and without UPQC at Different Locations

Location of measurement of % THD	%THD without UPQC of three phases		%THD with conventional UPQC of three phases		%THD of intelligent control UPQC of three phases	
At GRID	V_a	0	V_a	0	V_a	0
	V_b	0	V_b	0	V_b	0
	V_c	0	V_c	0	V_c	0
	I_a	5.35	I_a	2.52	I_a	0.10
	I_b	7.52	I_b	1.43	I_b	0.12
	I_c	5.93	I_c	2.05	I_c	0.07
At PCC (Point of common coupling)	V_a	0.97	V_a	0.12	V_a	0
	V_b	1.11	V_b	0.07	V_b	0
	V_c	1.00	V_c	0.11	V_c	0
	I_a	5.35	I_a	2.53	I_a	0.14
	I_b	7.51	I_b	1.43	I_b	0.17
	I_c	5.92	I_c	2.06	I_c	0.10
At T/F location	V_a	1.05	V_a	0.13	V_a	0
	V_b	1.20	V_b	0.08	V_b	0
	V_c	1.07	V_c	0.12	V_c	0
	I_a	5.34	I_a	2.53	I_a	0.15
	I_b	7.51	I_b	1.43	I_b	0.17
	I_c	5.92	I_c	2.05	I_c	0.10
At point of connection of Load with line	V_a	2.66	V_a	0.33	V_a	0.15
	V_b	3.02	V_b	0.17	V_b	0.15
	V_c	2.76	V_c	0.30	V_c	0.15
	I_a	5.34	I_a	2.54	I_a	0.31
	I_b	7.50	I_b	1.44	I_b	0.37
	I_c	5.91	I_c	2.06	I_c	0.22
At extreme load side	V_a	2.66	V_a	0.33	V_a	0.15
	V_b	3.02	V_b	0.17	V_b	0.15
	V_c	2.76	V_c	0.30	V_c	0.15
	I_a	2.55	I_a	0.32	I_a	0.15
	I_b	2.92	I_b	0.17	I_b	0.15
	I_c	2.65	I_c	0.29	I_c	0.15

Note: The readings of results marked in red colour are beyond the permissible limit which is 5% according to IEEE standards

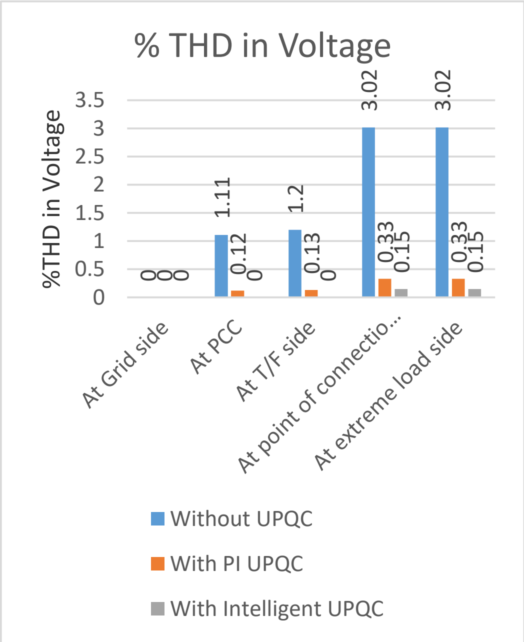

Fig. 9 Comparison table of %THD in voltage at different locations with and without UPQC

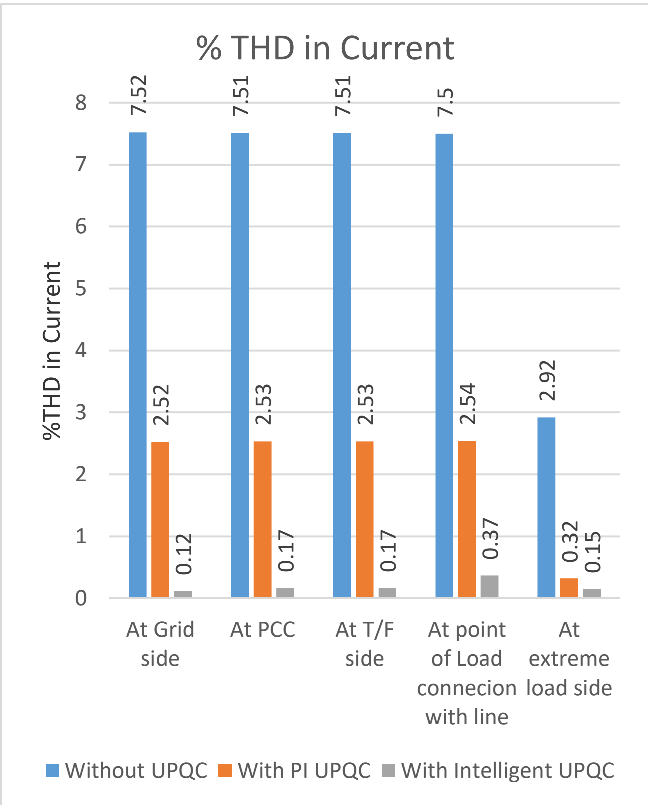

Fig. 10 Comparison table of %THD in current at different locations with and without UPQC

Note: For comparison %THD is taken as the maximum value of %THD among all the three phase

From the above table 1 and figures 9,10 it can be well observed that %THD in voltage are well within limits with all the three cases but it was considerably removed by the conventional controller but with intelligent controller it was fully removed and the %THD is equal to 0-0.15%. In the current %THD is beyond the limit without UPQC which is brought down to a range of about 2.52-2.92% with conventional UPQC but intelligent controlled UPQC has shown better results with %THD approximately equal to 0.12-0.37% which is quite good for the system.

V. CONCLUSION

From the above discussion it can be concluded that in the case of voltage the %THD is well within permissible limits with all the three cases i.e. without UPQC, with conventional UPQC and with intelligent UPQC, but the results shows that the intelligent UPQC has better efficiency than the conventional UPQC and improved performance, In the case of current the conventional UPQC and intelligent UPQC have shown significant improvement in the power quality as shown in the graph, but the results of intelligent controlled UPQC are best in case and are also improved as compared to conventional UPQC. Overall it can be concluded that the intelligent UPQC has improved performance as compared to the conventional UPQC.

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