Harmonic Mitigation Methods for Wind Energy Conversion Systems
Abhilash Barapatre 1, M. V. Jape 2
Department of Electrical Engineering
Government College of Engineering, Amravati, Maharashtra, India

Abstract:
Wind power capacity has experienced tremendous growth in the past decade. There are many loads (such as remote villages, islands, ships etc) that are away from the main grid. They require stand-alone generator system (which can provide constant nominal voltage and frequency) to provide for their local electrification. This requirement has lead to widespread research on development of new technologies for stand-alone generators. Renewable energy sources are alternative energy source, can bring new challenges when it is connected to the power grid. Generated power from wind energy system is always fluctuating due to the fluctuations in the wind. According to the guidelines specified in IEC-61400 standard (International Electro-technical Commission) provides some norms and measurements. The performance of the wind turbine, power quality is determined. The power quality measurements are-the active power, reactive power, voltage sag, voltage swell, flicker, harmonics, and electrical behavior of switching operation and these are measured according to national/international guidelines. The paper clearly shows the existence of power quality problem due to installation of wind turbine with the grid. In this System Inverter control strategy is used to reduce the power quality problems. Simulation results are presented to demonstrate the impact of integration of wind generating system with the grid and the effectiveness of the power quality solution. This control scheme for the grid connected wind energy generation system to improve the power quality is simulated using MATLAB/SIMULINK in power system block set.

Index Terms: Power Quality, Wind Generating System (WGS), Battery energy storage system (BESS)

I. INTRODUCTION
The need to integrate the renewable energy like wind energy into power system is to minimize the environmental impact on conventional plant. The integration of wind energy into existing power system presents requires the consideration of voltage regulation, stability, power quality problems. The power quality is an essential customer-focused measure and is greatly affected by the operation of a distribution and transmission network [1]. The need for providing reliable and secure power supply arises with an ever increasing demand for electricity. In recent years, the use of non-conventional sources for electricity generation has been gaining popularity and one such source is wind energy. The success of wind energy generating system lies in the capability of wind technology to be integrated into existing power system. However, the fluctuating nature of wind and the comparatively new types of its generators affect the power quality when the wind power is injected into the grid. In order to address the power quality issues that arise due to the integration of wind turbine with the grid, the grid operators have imposed stringent regulations requiring the wind turbines and wind farms to full fill power plant properties. This necessitates the use of highly sophisticated and flexible technology [2]. The performance of the wind turbine and thereby power quality are assessed through the guidelines specified by IEC-61400 standard. The power quality issues can be viewed with respect to the wind generation, transmission and distribution network, such as voltage sag, swells, flickers, harmonics etc. However the wind generator introduces disturbances into the distribution network. A proper control scheme in wind energy generation system is required under normal operating condition to allow the proper control over the active power production. In the event of increasing grid disturbance, a battery energy storage system for wind energy generating system is generally required to compensate the fluctuation generated by wind turbine. A STATCOM based control technology has been proposed for improving then power quality which can technically manages the power level associates with the commercial wind turbines. A simple control scheme based on hysteresis current control is developed for the STATCOM with the following objectives:

- Unity power factor at the source side.
- Minimize the percentage THD in source current waveform.

The paper is organized as follows. The Section II introduces the power quality standards, issues and its consequences of wind turbine. The Section III describes system development.

II. POWER QUALITY ISSUES AND ITS CONSEQUENCES

(A) Harmonics
The harmonic results due to the switching operation of power electronic converters. The harmonic voltage and current should be limited to the acceptable level at the point of wind turbine connection to the network [10].

(B) Voltage Sag (Or Dip)
A decrease of normal voltage level between 10 to 90% of the nominal rms voltage level at power frequency for duration of
0.5 cycles to one minute. It occurs due to connection of heavy loads and start-up of large motors.

(C) Voltage spikes

Very fast variation of the voltage values for durations from a several microseconds to few milliseconds. It occurs due to disconnection of heavy loads.

(D) Voltage Swell

Momentary increase of voltage, at the power frequency, outside the normal tolerances, with duration of more than one cycle and typically less than a few seconds. It is caused due to badly regulated transformers (mainly during off-peak hours).

(E) Voltage fluctuation

A series of voltage changes or a continuous variation of the R.M.S voltage. It is caused due to frequent start/stop of electric motors (for instance elevators), Oscillation in loads.

(F) Very Short Interruption

Total interruption of electrical supply for duration from few milliseconds to one to two seconds. It is caused due to insulation failure, lightning and insulator flashover.

(G) Long Interruptions

Total interruption of electrical supply for duration greater than 1 to 2 seconds. It occurs due to equipment failure in the power system network.

(H) Consequences of the issues

The voltage variation, flicker, harmonics causes the malfunction of equipment namely microprocessor based control system, programmable logic controller. It may lead to tripping of contractors, tripping of protection devices, stoppage of sensitive equipments like personal computer, programmable logic control system and may stop the process and even can damage of sensitive equipments. Thus it degrades the power quality in the grid [3]. The proposed system consists of RES connected to the dc-link of a grid-interfacing inverter as shown in Fig. 1. The voltage source inverter is a key element of a DG system as it interfaces the renewable energy source to the grid and delivers the generated power. The RES may be a DC source or an AC source with rectifier coupled to dc-link. Usually, the fuel cell and photovoltaic energy sources generate power at variable low dc voltage, while the variable speed wind turbines generate power at variable ac voltage. Thus, the power generated from these renewable sources needs power conditioning (i.e., dc/dc or ac/dc) before connecting on dc-link. The dc-capacitor decouples the RES from grid and also allows independent control of converters on either side of dc-link.

SYSTEM DEVELOPMENT

A. PMG BASED WECS BACKGROUND

In all of the existing systems based on PMGs, constant frequency output is obtained by converting the variable frequency output to DC and then converting this DC to constant AC. In a thyristor based grid-side inverter is proposed which allows continuous control of the inverter firing angle, hence, optimum energy capture was obtained. Advantages of this scheme include lower device cost and higher available power rating than hard-switched inverters. A major drawback to this inverter is the need for an active compensator for the reactive power demand and harmonic distortion created. Another WECS was proposed in which control involves the manipulation of the modulation index of the reference sinusoidal signal applied to the PWM generator. This is achieved by determining the DC-link voltage by a power mapping technique that contains the maximum power versus DC voltage characteristic. The control system is further improved by using a derivative control on the stator frequency, since it also changes with change in DC-link voltage. The use of a Voltage Source Inverter (VSI) accompanied by a DC/DC converter was proposed. The use of two, 6-switch, hard-switched converters and DC-link capacitor has been explored. The generator side rectifier is controlled through a PI controller to obtain maximum electrical torque with minimum current. One of the most common problems when connecting small renewable energy systems to the electric grid is the injection of harmonic components that may deteriorate the power quality. In this paper a small scale WECS which employs an uncontrolled bridge rectifier, CLBC and a TBFW inverter is introduced. The incorporation of TBFW inverter facilitates compensation for power quality disturbances and reactive power demand.

DC-Link Voltage and Power Control Operation

Due to the intermittent nature of RES, the generated power is of variable nature. The dc-link plays an important role in transferring this variable power from renewable energy source to the grid. RES are represented as current sources connected to the dc-link of a grid-interfacing inverter. Fig. 5 shows the systematic representation of power transfer from the renewable energy resources to the grid via the dc-link. The current injected by renewable into dc-link at voltage level can be given as

![Figure 2: Schematic wind energy conversion system.](http://ijesc.org/)
3.3.2 WIND POWER CONVERTER MODELING

The wind power conversion system studied has the configuration shown in Fig. 6. The system consists of a wind turbine, a high pole number modular PM generator a modular rectifier system and a controllable power electronics inverter. The modeling and simulation of these elements are discussed below.

A. Wind Modeling

Wind is an intermittent and variable source of energy. Wind speed varies with many factors and is random in magnitude and direction. For this study, the wind is simulated with four components, namely, base component, ramp component, gust component and noisy component as:

\[ V_{\text{wind}} = V_{\text{base}} + V_{\text{ramp}} + V_{\text{gust}} + V_{\text{noise}} \] (m/s)

B. Wind Turbine Characteristics

The power in the wind is proportional to the cube of the wind speed. However, only part of the wind power is extractable. Although a complete aerodynamic model of the wind turbine could simulate the interaction between the wind and the turbine blades in detail, the simple expression of, which is quite often used to describe the mechanical power transmitted to the hub shaft, is sufficient for this study

\[ P_{\text{turbine}} = 0.5 \cdot \rho \cdot A \cdot C_p \cdot V_{\text{wind}}^3 \]

Where \( \rho \) (kg/m) is the air density
And \( A \) (m) is the area swept out by the turbine blades, \( C_p \) a dimensionless power coefficient depends on the type and operating condition of the wind turbine.

Figure 3. Characteristics of Turbine Power

3.4 Control Strategy for Grid Interfacing Inverter

Voltage oriented control (VOC) is mostly used for grid converters. In VOC coordinate transformation between the stationary and the synchronous reference frames is done to control grid side converter. A phase locked loop (PLL) is used for guaranteed fast transient response and high static performance due to internal control loops. Grid currents is converted in two orthogonal axes currents to provide separate control for active and reactive power and an high power factor and sinusoidal grid currents can be obtained.

B. WECS WITH POWER QUALITY IMPROVEMENT FEATURES

A block diagram of the proposed system is shown in Fig and schematic diagram of the system is shown in Fig. 3. The wind turbine is the prime mover of the PMG. As wind velocity is non-uniform, the output of the PMG will be fluctuating in nature. Therefore it cannot be directly interfaced to the grid. In the proposed WECS, the PMG output is converted to DC using full bridge rectifier and is maintained at a steady value using Closed Loop Boost Converter (CLBC). This constant DC output is converted to AC using Grid coupled inverter. The inverter is controlled using Digital Control System (DCS). The DCS senses line voltages and DC link voltage and uses hysteresis current control method to produce switching signals of the inverter. The inverter can thus be utilized as a power converter injecting power generated from PMG to the grid. It also serves as a shunt active power filter to compensate for power quality disturbances such as load current harmonics and load reactive power demand even at low generation.

Figure 4. Proposed system

Figure 5. Schematic diagram of the proposed WECS

C. Generation

Permanant magnet excitation is new trends in small scale WECS since it has higher efficiency and smaller wind turbine blade diameter. The primary advantage of PMG is that they do not require any external excitation current. Due to the absence of the field losses they have better thermal characteristics. They are more reliable due to the absence of slip rings. PMGs are lighter therefore they have higher power to weight ratio.
D. AC-DC and DC-DC Conversion

The 3 phase full bridge diode rectifier converts 3 phase AC generated by PMG to DC. Magnitude of DC varies with change in AC input. The varying DC output of the three phase rectifier is maintained constant with the help of a closed loop DC-DC converter. Closed loop boost converter steps up variable DC to constant DC. In the proposed system, a PI controller based closed loop boost converter is used. Its output remains constant even if there are variations in the input voltage. Closed loop control is obtained by comparing the reference signal (measure of the desired output voltage) with the output of the boost converter. The duty ratio of the boost converter is varied to compensate the variations in the input voltage. Therefore output voltage is kept at a desired value.

E. Grid interfacing inverter

Inverter incorporates the features of APF in the conventional interfacing inverter. The inverter can perform the following functions:

1) Transfer of active power from the generator to the load/grid
2) Reactive power demand support
3) Current unbalance, current harmonics compensation

With adequate control of grid-interfacing inverter, all the objectives can be accomplished either individually or simultaneously. The Power quality constraints can therefore be strictly maintained within the utility standards without additional hardware cost. Control strategy for grid side inverter is shown in Fig. 4.

\[
U_a = \sin \theta \\
U_b = \sin(\theta - 2\pi/3) \\
U_c = \sin(\theta + 2\pi/3)
\]

The actual DC-link voltage is sensed and compared with reference DC-link voltage. The difference of this DC-link voltage and reference DC-link voltage \( (V_{dc^*}) \) is given to a discrete-PI regulator to maintain a constant DC-link voltage. The output of the discrete-PI regulator is \( I_n \). The instantaneous values of reference three phase grid currents are computed as,

\[
I_{a^*} = I_n \cdot U_a \\
I_{b^*} = I_n \cdot U_b \\
I_{c^*} = I_n \cdot U_c
\]

The reference grid currents (\( I_{a^*}, I_{b^*} \) and \( I_{c^*} \)) are compared with actual grid currents (\( I_a, I_b \) and \( I_c \)) to compute the current errors which are given to the hysteresis current controller. The hysteresis controller then generates the switching pulses (P1 to P6) for the gate terminals of grid-interfacing inverter.

F. GRID PARAMETERS

<table>
<thead>
<tr>
<th>Three phase voltage source</th>
<th>Voltage = 33kV (RMS), ( f_n = 50 ) Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Series RLC load</td>
<td>( V_n = 415 ) V, ( f_n = 50 ) Hz, ( P = 1000W ).</td>
</tr>
</tbody>
</table>

IV. SIMULATION RESULTS

In order to validate the performance of the proposed system, an extensive simulation study was done by using MATLAB. The system was tested with different load and source voltages and the voltages were measured at different points in the simulation circuit. The designed system generates AC power with a PMG 50Hz. This variable frequency, variable magnitude three-phase AC is converted to DC by using a three phase rectifier.
This DC voltage is then boosted with a closed loop boost converter (CLBC) which uses PWM technique to regulate the DC voltage. Output of the closed loop boost converter is shown in Fig. 8. This output will be always constant. This DC voltage is then converted to three phase AC using grid interfacing inverter. A Three-leg inverter is actively controlled to achieve sinusoidal grid currents despite highly unbalanced non-linear load. PMG with regulated output is connected on the dc link of grid interfacing inverter. Initially the grid interfacing inverter is not connected to the network. The waveforms of grid voltages, grid currents, load voltages, load currents and inverter currents are shown in Fig. 5. At this time the grid current profile is identical to the load current profile when inverter is not connected to the grid. Figure 9 shows the waveforms of grid voltages, grid currents, load voltages, load currents and inverter currents when inverter is connected to the system. When the inverter is connected to the grid, it injects active power generated from the PMG. Since the generated power is more than the load power demand, the additional power is fed back to the grid. The grid interfacing inverter also supplies the load reactive power demand locally. Thus when inverter is in operation the grid only supplies/receives fundamental active power.
V. CONCLUSIONS

This paper focuses on power quality improvement of a small scale WECS which uses PMG for generation. In the proposed system, the output of the PMG is converted to constant DC using a full bridge rectifier and a closed loop boost converter. This constant DC output is converted to AC using a grid interfacing inverter. By suitable control of grid interfacing inverter, it can function as shunt active filter for compensating the power quality disturbances present in the system and thereby power quality of the system can be improved. The proposed system is designed in such a manner that it can incorporate the features of APF in the conventional inverter interfacing renewable energy sources with the grid, without any additional hardware cost. Extensive simulation study is done by using MATLAB/Simulink to validate the proposed approach. The simulation results demonstrate that the output of the boost converter remains constant even though the output of the PMG is fluctuating. And also the grid interfacing inverter is controlled in such a manner that the power quality issues such as current unbalance, current harmonics and load reactive power due to unbalanced and non-linear loads are effectively compensated and the grid side currents are maintained as balanced and sinusoidal.

VI. REFERENCES


[9]. Jinwei He, Md. Shirajum Munir, and Yun Wei Li “Opportunities for Power Quality Improvement through DG-Grid Interfacing Converters” The 2010 International Power Electronics Conference


[15]. Siyu Leng*, II-Yup Chung*, and David A. Cartes “Distributed Operation of Multiple Shunt Active Power Filters Considering Power Quality Improvement Capacity” in 2010 2nd IEEE International symposium on power electronics for distributed generations.


