AUXILIARY PARALLEL GRIDSIDE CONVERTER BASED POWER QUALITY IMPROVEMENT IN PMSG WIND MILL SYSTEM

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Abstract
Wind power is proposed as one of the main new power sources and is day by day gaining more and more importance. In last few decades, different types of wind turbines are developed to increase the maximum power capture with minimum cost and expansion for use of wind turbine for onshore and offshore applications. The integration of these systems (wind energy, hydro energy, solar power etc.) created different kinds of problems in the grid like system stability problems or power quality issues which needs to be resolved In this paper simulation of auxiliary parallel grid-side converter topology is done using MATLAB/Simulink to realize improvement in power quality .

Index Terms: Induction generators, Synchronous generators, onshore/offshore wind turbine, power quality, Permanent magnet generators, Power quality, multiple converters, matrix converters, z- source inverter

1. INTRODUCTION

Power Quality (PQ) related issues are of most concern. The widespread use of electronic equipment ,such as information technology equipment, power electronics such as adjustable speed drives (ASD), programmable logic controllers (PLC), energy-efficient lighting, led to a complete change of electric loads nature. These loads are simultaneously the major causers and the major victims of power quality problems. Due to their non-linearity, all these loads cause disturbances in the voltage waveform. Along with technology advance, the organization of the worldwide economy has evolved towards globalization and the profit margins of many activities tend to decrease. The increased sensitivity of the vast majority of processes (industrial, services and even residential) to PQ problems turns the availability of electric power with quality a crucial factor for competitiveness in every activity sector. The most critical areas are the continuous process industry and the information technology services.

When a disturbance occurs, huge financial losses may happen, with the consequent loss of productivity and competitiveness. Although many efforts have been taken by utilities, some consumers require a level of PQ higher than the level provided by modern electric networks. This implies that some measures must be taken in order to achieve higher levels of Power Quality.

Use of renewable energy has increased through time and integration of renewable energy such as wind, photovoltaic, fuel cell, and tidal to the grid solved many problems and replenished the exceeding and ascending need for electrical energy. Integration of the renewable energy with the grid has lead to a more complex electrical network or “Grid”.

The integration of wind energy into a weak system is a challenge; voltage fluctuation, voltage dips, swells and swags are created due to the uncontrollable resource and the nature of the DWIG (Distributed Wind Induction Generators) on the already weak system. This causes stability issues, reliability and power quality issues which need to be solved The issue of power quality is of great importance to the to the wind turbine [6]. and there's a need to find solutions to these problems, using different technologies such as smart meters, monitoring system, controllers, remote ability.

Direct drive system like PMSG has many competitive advantages over other direct drive system because of its great energy yield, noise reduction, good reliability and high efficiency [6], [7]. Currently many topologies are used in stand-alone and grid connected wind energy conversion system.

This paper is organized as follows. Section 2 reviews the PMSG wind energy conversion system , Section 3 discusses the power quality issues, Section 4 talks about improvement techniques followed by result analysis in Section 5 and conclusion in Section 6.

2. PMSG WIND ENERGY CONVERSION SYSTEM

Blades of the wind turbines are designed aerodynamically; they capture power from the wind and convert wind power into the mechanical power [8]. A gear box is used to match the speed of wind turbine and generator. PMSG is a direct-drive type system so it's used to eliminate the gear box and reduces the size of wind energy conversion system [9]. After converting the mechanical wind energy into electrical energy by the generator, power converters are included for conversions of generated AC power into DC power (either for storing energy in battery or supplying dc power to resistive loads) or in AC/DC/AC system supplying AC power grid coupled systems. Various topologies of converter used with PMSG base wind energy conversion system for high efficiency and low cost [2].

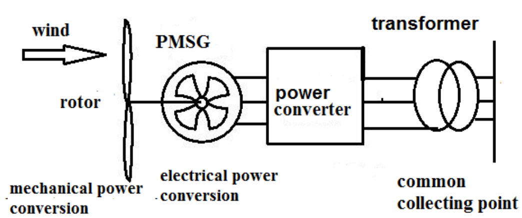

Figure 1 Wind Energy Conversion System for PMSG

3.POWER QUALITY ISSUES

Various power quality issues that normally occur in a power system are listed below

a)Voltage Sag

Description: A decrease of the normal voltage level between 10 and 90% of the nominal rms voltage at the power frequency, for durations of 0,5 cycle to 1 minute.

Causes: Faults on the transmission or distribution network (most of the times on parallel feeders). Faults in consumer's installation. Connection of heavy loads and start-up of large motors.

Consequences: Malfunction of information technology equipment, namely microprocessor-based control systems (PCs, PLCs, ASDs, etc) that may lead to a process stoppage. Tripping of contactors and electromechanical relays. Disconnection and loss of efficiency in electric rotating machines.)

b)Very Short Interruptions

Description: Total interruption of electrical supply for duration from few milliseconds to one or two seconds.

Causes: Mainly due to the opening and automatic reclosure of protection devices to decommission a faulty section of the network. The main fault causes are insulation failure, lightning and insulator flashover.

Consequences: Tripping of protection devices, loss of information and malfunction of data processing equipment. Stoppage of sensitive equipment, such as ASDs, PCs, PLCs, if they're not prepared to deal with this situation.

c) Long Interruptions

Description: Total interruption of electrical supply for duration greater than 1 to 2 seconds

Causes: Equipment failure in the power system network, storms and objects (trees, cars, etc) striking lines or poles, fire, human error, bad coordination or failure of protection devices.

Consequences: Stoppage of all equipment.

d) **Voltage Spike**

Description: Very fast variation of the voltage value for durations from a several microseconds to few milliseconds. These variations may reach thousands of volts, even in low voltage.

Causes: Lightning, switching of lines or power factor correction capacitors, disconnection of heavy loads.

Consequences: Destruction of components (particularly electronic components) and of insulation materials, data processing errors or data loss, electromagnetic interference.

e) Voltage Swell

Description: Momentary increase of the voltage, at the power frequency, outside the normal tolerances, with duration of more than one cycle and typically less than a few seconds.

Causes: Start/stop of heavy loads, badly dimensioned power sources, badly regulated transformers (mainly during off-peak hours).

Consequences: Data loss, flickering of lighting and screens, stoppage or damage of sensitive equipment, if the voltage values are too high.

f) Harmonic Distortion

Description: Voltage or current waveforms assume non-sinusoidal shape. The waveform corresponds to the sum of different sine-waves with different magnitude and phase, having frequencies that are multiples of power-system frequency.

Causes: *Classic sources*: electric machines working above the knee of the magnetization curve (magnetic saturation), arc furnaces, welding machines, rectifiers, and DC brush motors. *Modern sources*: all non-linear loads, such as power electronics equipment including ASDs, switched mode power supplies, data processing equipment, high efficiency lighting.

Consequences: Increased probability in occurrence of resonance, neutral overload in 3-phase systems, overheating of all cables and equipment, loss of efficiency in electric machines, electromagnetic interference with communication systems, errors in measures when using average reading meters, nuisance tripping of thermal protections.

g)Voltage Fluctuation

Description: Oscillation of voltage value, amplitude modulated by a signal with frequency of 0 to 30 Hz.

Causes: Arc furnaces, frequent start/stop of electric motors (for instance elevators), oscillating loads.

Consequences: Most consequences are common to undervoltages. The most perceptible consequence is the flickering of lighting and screens, giving the impression of unsteadiness of visual perception.

h)Noise

Description: Superimposing of high frequency signals on the waveform of the power-system frequency.

Causes: Electromagnetic interferences provoked by Hertzian waves such as microwaves, television diffusion, and radiation due to welding machines, arc furnaces, and electronic equipment. Improper grounding may also be a cause.

Consequences: Disturbances on sensitive electronic equipment, usually not destructive. May cause data loss and data processing errors.

i) Voltage Unbalance

Description: A voltage variation in a three-phase system in which the three voltage magnitudes or the phaseangle differences between them are not equal.

Causes: Large single-phase loads (induction furnaces, traction loads), incorrect distribution of all single-phase loads by the three phases of the system (this may be also due to a fault).

Consequences: Unbalanced systems imply the existence of a negative sequence that is harmful to all three phase loads. The most affected loads are three-phase induction machines

4. POWER QUALITY IMPROVEMENT CONVERTER TOPOLOGIES IN PMSG APPLICATION

Power converters are used in WECS for converting generated power. The development of power electronics and their applicability in wind energy extraction allowed for variable speed operation of the wind turbine. Two main converter topologies of power converter with PMSG are Standalone topology and Grid connected topology.

A. Grid side Converter:

Converters used in grid side are thyristor converters. They have high power capacity and mainly used in high power applications.

B. Standalone Converter:

Standalone converter system used PWM control method general. IGBT is mainly used semi-conductor because of turn- off capability. PWM converter may produce harmonics and interharmonics due to high frequency switching. Filters are connected to remove harmonics [9].

Grid connected topologies with PMSG are classified on the basis of ***Grid side converters***:

1. Thyristor grid side converter
2. Hard switched grid side converter
3. Matrix converter
4. Multilevel converter
5. Z-source inverter

1. Thyristor grid side converter:

A thyristor grid side inverter allows continuous control of inverter firing angle [10]. To obtain the optimum energy thyristor grid side inverters regulate turbine speed by the DC link voltage. A voltage source converter (VSC) is used for the compensator and the error signal between the reference and actual compensator current is used to drive the pulse width modulated (PWM) control [11].

Advantages:

Lower cost and higher power rating.

Disadvantages:
Need of an active compensator for reactive power demand and reduction in total harmonic distortion.

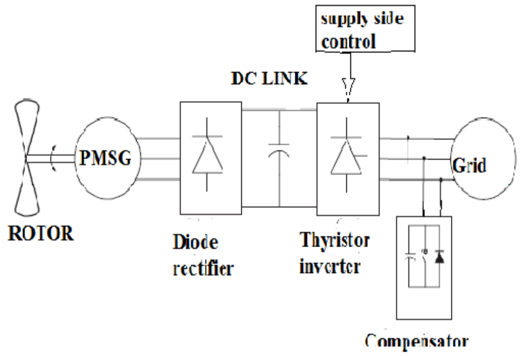

Figure 2 Thyristor Grid Side Converter

2. Hard switched grid side converter:
To maximize the system's power output a power mapping technique is used to match the Maximum Power to the DC-link voltage. Furthermore, a derivative control is also used to control the stator frequency as it changes with the DC-linked voltage. The control system is like the MPPT (Maximum Power Point Tracking) which maps the Power generated to a reference power so as to set the operating DC voltage.

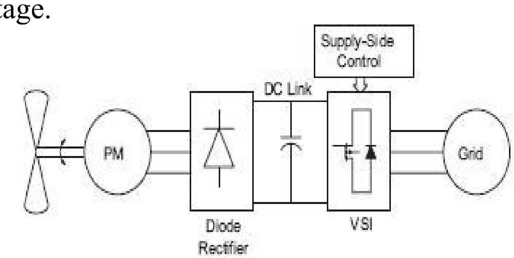

Figure3. Hard Switching Supply Side Inverter with Voltage Source Inverter (VSI)
Following topologies are being use with grid side PWM converters:
a) Back to back PWMVSI:
Back to back PWM converter is the most conventional type converter. It is referred as two levels PWM-VSI converter because two voltage source inverter (VSI) are connected in generator side and grid side. A DC link capacitor is connected between two PWM-VSI. DC link capacitor is also called decoupling capacitor and provide a separate control in the inverter on the generator side and grid side [16].

Advantages: Lower cost.
Disadvantages:
Switching losses and emission of high frequency harmonics.
Decoupling capacitor reduces life of the system.

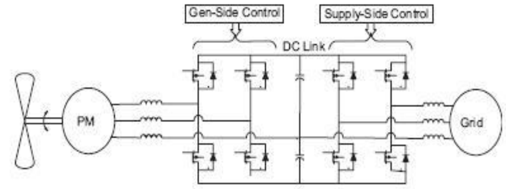

Figure 4 Back to Back PWM VSI Converter

b) Generator side uncontrolled rectifier with boost converter:
In this topology, output of PMSG is rectified by an uncontrolled rectifier and MPPT is achieved by a boost converter. *Advantages:*
No need of wind measurement.
Controller adapts to the parameter variations of the PMSG.

Figure 5 Generator Side Uncontrolled Rectifier With Boost Converter

c) Generator Side Phase Shifting Transformer feeding Series Type 12 Pulse Uncontrolled Rectifier:
This type of inverter used to a novel and simple MPPT control strategy. In generator terminal a passive filter is connected to reduce harmonics and improve efficiency.
Advantages:
Provide high efficiency and suppress distortions presents in the PMSG voltage and current.

d) Generator Side semi controlled Rectifier:
The main advantages of the topology are following:
- Simple circuit design, no complexity.
- No possible shoot through fault.
- High efficiency.
- Low cost.

3. *Matrix converter:*
Matrix converter is an AC-AC converter and an alternative of the DC link voltage-sourced converter. A matrix converter provides a large no. of control levers that allows for independent control on the output voltage magnitude, frequency, phase angle and input power factor [12].
Advantages:
Eliminate DC link reactive element, e.g. bulky capacitor and / or inductors.
No need of any large energy storage element.

High efficiency.

- Harmonic emission.

Disadvantages:

- Lack of decoupling between the two sides of the converter.
- Low voltage gain.
- Higher conducting losses
- Due to complex control it has not accepted in industrial application.

Some different types of matrix converter are following:

a) Conventional matrix converter:

The conventional matrix converter is composed with nine bi-directional commanded insulated gate bipolar transistors (IGBT) [13]. Proper operation of switches in the matrix control on the output of magnitude, frequency, phase angle and input displacement angle.

Disadvantages:

Commutation problem associated during the operation of the switches.

Safe operation of the switches requires complicated switching.

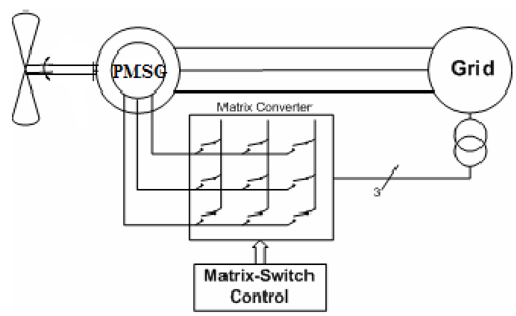

Figure 6 Conventional Matrix Converter

b) Improved matrix converter:

Improved matrix converter is based on the concept "Fictitious DC link" used in controlling the matrix converter. There is no energy storage element between line side and load side converter [12]. The matrix convert is connected between two filters and PMSG is connected with first order type filter and second order type filter is connected with an electric network [13].

Advantages:

Commutation problem associated with the switches have been solved.

All the switches at the line-side turn-on and turn-off at Zero current

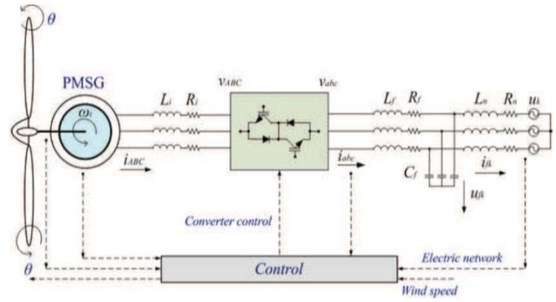

Figure 7 Improved Matrix Converter

4. Multilevel converter:

Multilevel converters are mainly used in high power variable wind power applications [14]. Multilevel converter includes an array of power semiconductors and capacitor voltage sources, the output of which generate voltages with stepped waveform [15]. *Advantages:*

- Divide the total voltage into multiple voltages which results in a lower$dvdt$.
- Draw input current with very low distortion.
- Can operate with a lower switching frequency and reduce switching losses.

Disadvantages:

- Voltage imbalanced due to link capacitor.
- High cost because of number of switches.
- Complex control.
- Uneven current stress on the switches due to its circuit design characteristics [16].

Types of Multilevel converters are following:

a) Neutral clamped or diode clamped converter (NPC):

Neutral clamped type converter can be structured as 3-level, 5-level and even 7-level or more, the 3-level NPC is the most applied type in industry [17]. There are four switches in 3-level NPC which are applied with diodes to a midpoint of the capacitor bank. To this converter all conventional (PWM) approaches are applicable [18]. *Advantages:*

- The output line to line voltage of the NPC converter consist of 3voltage level, which result in reduced harmonic in the output voltage and increase power quality.

Disadvantages:

- Power losses on the power switches are unevenly distributed which decrease the reliability of the NPC.

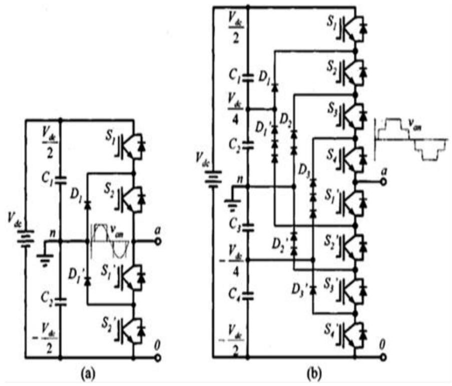

Figure 8 Neutral clamped or diode clamped converter a)3 level b) 5 level

b) Flying capacitor converter (FCC):

Flying clamped capacitors are popular due to neutral voltage balance property. 3-level and 5-level type FCC are used in applications but 5-level type FCC is more popular because of more flexibility than a NPC.

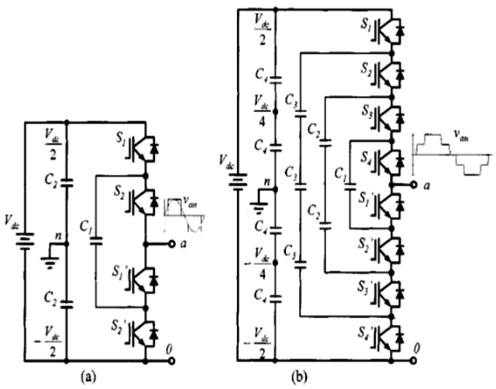

Figure 9 Flying Capacitor Converter a)3 level b)5 level *c) Cascade H Bridge (CHB)*:

Cascade H Bridge is a modulator converter and consists of several blocks of H bridge cells in series. This series connected power cells increase the voltage and power levels of the CHB. Each H bridge block is constructed with diodes in anti-parallel [19].

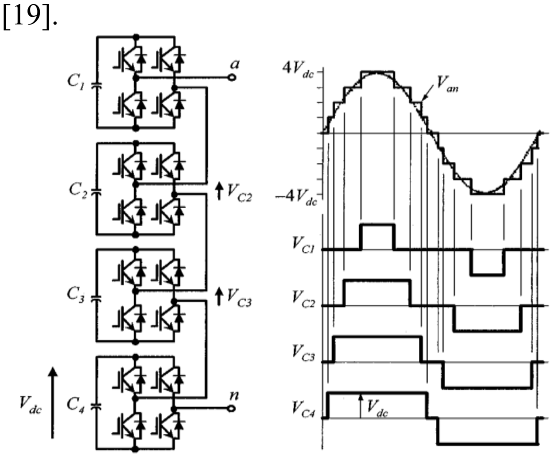

Figure 10 Clamped Capacitor Converter

Disadvantage:

- It requires large numbers of DC sources for the H-bridge which increases the cost [18].

5. Z-Source inverter (ZSI):

Z-source inverter is used for maximum power tracking control and delivering power to grid [20]. ZSI is an alternative power concept as it can have both voltage buck and boost capabilities [21]. *Advantages:*

- Less effected by the EMI noise and mis-gating.
- Harmonic distortion is low.
- No of switching semiconductors is reduced.
- Reliability of the system is improved

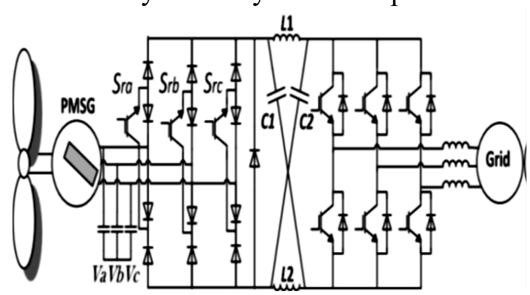

Figure 11 Z -Source Inverter

Fig. shows the main circuit of ZSI. It employs an impedance network coupled between the power sources and the converter that consists of split inductor $L1$ and $L2$ and capacitor $C1$ and $C2$ connected in X shape [21].

Standalone side converter:

Main objective of the standalone wind energy conversion system is the control of load frequency and voltage [22]. Standalone system is useful in remote area where power grid is not feasible. Generally DC-DC converters are used in the standalone system. DC-DC converters are implemented between the rectifier and the battery. DC-DC converters used in standalone side are following:

1. DC boost converter.
2. DC buck-boost converter.

1. DC boost converter:

DC boost converter is step up type converter. DC boost converters enhance the production in the high range [23]. DC-DC boost converter is used to regulate the battery bank current in order to achieve maximum power from the wind. Boost converter acts as an interface between the full wave rectifier bridge and the battery bank [24].

2. DC buck-boost converter:

A buck-boost converter can be obtained by the cascade connection of the two basic converters, the step-down converter and the step-up converter. Buck-boost converter controls the rotor speed.

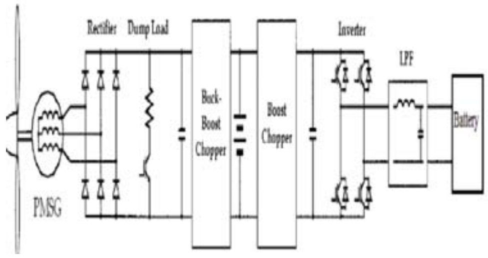

Figure 12 DC Boost & DC Buck –Boost with PMSG

5. **Results with Proposed Model**

The proposed Model with Auxilliary parallel Gridside converter which allows continuous control of firing angle [10]. To obtain the optimum energy thyristor grid side inverters regulate turbine speed . A voltage source converter (VSC) is used for the compensator and the error signal between the reference and actual compensator current is used to drive the pulse width modulated (PWM) control .

The proposed priority control block gives top priority to active power production than power quality, and reactive power compensation has priority than active filtering. After active power production and power factor correction, the capability of the GSC is fully exploited for active filtering, without its over-rating; by the calculation of an appropriate portion of rotor current commands in such a way to ensure a better filtering quality and keep the RSC current under its rated value. Simulation results prove the effectiveness of the proposed approach. The power output waveform as shown in figure 16 indicates steady state power output

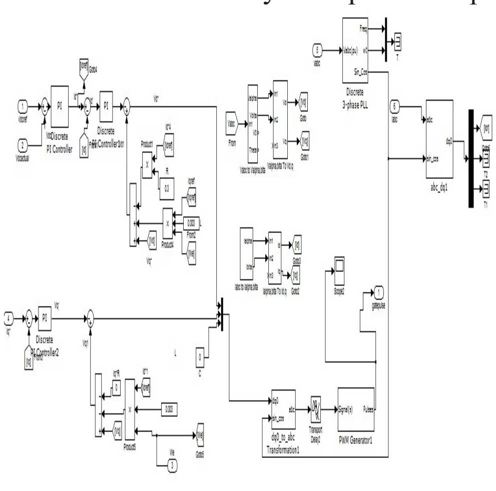

Figure 13 Proposed MATLAB Simulation model

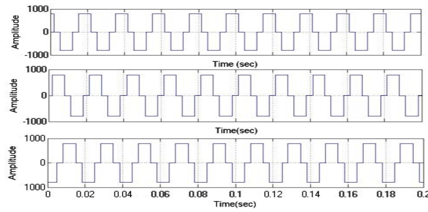

Figure 14Gridside Voltage Output

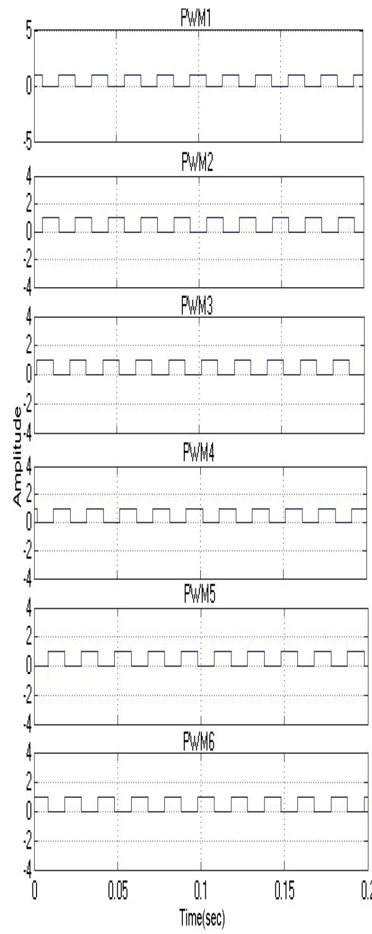

Figure 15 Gate pulse waveform of gridside converter

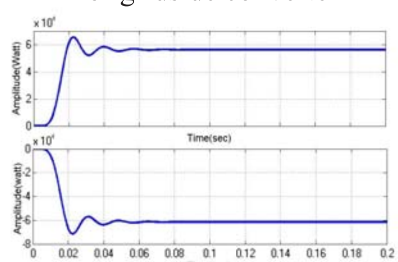

Figure 16 Active and Reactive Power Output waveform

6. Conclusion

Thus a novel approach has been proposed to manage and improve the quality of the grid power using a WECS equipped by a PMSG . The GSC is controlled in such a way to manage between production of maximum active power and power quality improvement without any over-rating. The proposed priority control block gives top priority to active power production than power quality, and reactive power compensation has priority than active filtering. After active power production and power factor correction, the capability of the GSC is fully exploited for active filtering, without its over-rating; by the calculation of an appropriate portion of rotor current commands in such a way to ensure a better filtering quality and keep the RSC current under its rated value. Simulation results prove the effectiveness of the proposed approach. A selective filter can be used to compensate only the fifth and seventh most dominant
harmonic currents, and guarantee a maximum capability of the GSC, in terms of active filtering, in the same way.

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