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MULTIFUNCTIONAL GRID CONNECTED INVERTER BY WIND ENERGY CONVERSION SYSTEM

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Abstract – Non-conventional mode of generation of electricity has several advantages over conventional sources of generation. It is eco-friendly, cost effective, damage free, long lasting and more over harmless. Electricity generation through wind energy is considered as socially beneficial and economically feasible for several applications. Domestic and industrial devices use more and more circuits having a non-linear behaviour. They create non-sinusoidal currents causing high harmonic currents in the distribution networks.

In the proposed method, a three-phase multifunctional grid-connected inverter interfaced with a wind energy conversion system (WECS) is introduced. This system consists of a permanent magnet synchronous generator (PMSG) based wind turbine, a rectifier and a three-phase voltage source inverter connected to the utility at the point of common coupling. To ensure the multifunctional feature, we propose a direct power control (DPC) which is applied to eliminate line current harmonics, compensate reactive power and feeding wind power into the utility.

The simulation results show that the control algorithm of system is effective for eliminating harmonic currents, reactive power compensation and inject the active power available from the PMSG wind turbine into the load and/or grid.

Key Words: Wind Energy Conversion System, Double Fed Induction Generator, Self-Excited Induction Generator, Self-Excited Induction Generator, Permanent Magnet Synchronous Generator, Shunt Active Power Filter, Static Compensator, Voltage and Frequency Controller, Photo Voltaic Generator.

1.INTRODUCTION

Non-conventional mode of generation of electricity has several advantages over conventional sources of generation. It is eco-friendly, cost effective, damage free, long lasting and more over harmless. Electricity generation through wind energy is considered as socially beneficial and economically feasible for several applications. In a year many large utility scale wind power plants are installed. There are different components of a Wind Energy Conversion System (WECS), of which the most important is the type of generator used. There are several types of generators used such as doubly fed Induction generator (DFIG), Self-excited induction generator (SEIG), and permanent magnet synchronous generator (PMSG). Among these generators, PMSG has several advantages, which make it very usable for WECS.

Domestic and industrial devices use more and more circuits having a nonlinear behaviour. They create, in the distribution networks, non-sinusoidal currents causing high harmonic currents. This result in the reduction of power factor, reduces the efficiency and reduces the system performs. Traditionally, the simplest method to eliminate current harmonics and to increase the power factor is the usage of passive LC. However, the use of passive filter has many disadvantages. Recently, because of the rapid progress in modern power electronic technology, the previous works were oriented mostly on the active filters instead of passive filters. The shunt active power filter (SAPF) is one of the most popular active filters.

The direct power control (DPC) technique for a multifunctional grid- connected inverter interfaced with a wind energy conversion system (WECS). The main purpose of DPC is to control the amplitude of the instantaneous active and reactive powers to generate the switching moments of the inverter switches. The active power command is provided from a dc-bus voltage controller block, while the reactive power command is directly given from the outside of the controller. Errors between the commands and the estimated feedback power are input to the hysteresis comparators. Inner current control loops and PWM modulator are not required in DPC because the converter switching states are selected by a switching table based on the instantaneous errors between the commanded and estimated values of active and reactive powers.

The overall control system of a multifunctional grid connected inverter interfaced with a wind energy conversion system is built in the Matlab / Simulink environment. Then, the simulations results are provided to validate the correctness of the adopted control system.

1.1 OBJECTIVE

The objectives of research are listed below,
(i) To develop MATLAB Simulink model for grid connected wind turbine generator based on permanent magnet synchronous generator (PMSG) subject to presence of harmonic with nonlinear loads.
(ii) To design PI controller based APF to tackle harmonic problems in the proposed system under unbalanced nonlinear loads.
(iii) To design Direct Power Control to control the amplitude of the instantaneous active and reactive powers to generate the switching moments of the inverter switches.

2. PROPOSED METHOD

2.1 WIND ENERGY CONVERSION SYSTEM:

The generators used for the wind energy conversion system mostly of either doubly fed induction generator (DFIG) or permanent magnet synchronous generator (PMSG) type. DFIG have windings on both stationary and rotating parts, where both windings transfer significant power between shaft and grid. In DFIG the converters have to process only about 25-30 percent of total generated power (rotor power connected to grid through converter) and the rest being fed to grid directly from stator. Whereas, converter used in PMSG has to process 100percent power generated, where 100 percent refers to the standard WECS equipment with three stage gear box in DFIG. Majority of wind turbine manufacturers utilize DFIG for their WECS due to the advantage in terms of cost, weight and size. But the reliability associated with gearbox, the slip rings and brushes in DFIG is unsuitable for certain applications. PMSG does not need a gear box and hence, it has high efficiency with less maintenance. The PMSG drives achieve very high torque at low speeds with less noise and require no external excitation. In the present trend WECS with

multibird concept is interesting and offers the same advantage for large systems in future. Multibird is a technology where generator, gearbox, main shaft and shaft bearing are all integrated within a common housing. This concept allows reduce in weight and size of generators combined with the gear box technology. The generators with multibird concept become cheaper and more reliable than that of the standard one, but it loses its efficiency. It is the equipment that converts and then stores or transfers energy from the wind into usable forms of energy and includes, but not limited to, base, blade, foundation, generator, nacelle, rotor, wind tower, transformer, turbine, vane, wind farm collection system, meteorological towers, communications facilities, electrical cabling or other components related to the system.

2.1.1 PERMANENT MAGNET SYNCHRONOUS GENERATOR:

A permanent magnet synchronous generator is a generator where the excitation field is provided by a permanent magnet instead of a coil. The term synchronous refers here to the fact that the rotor and magnetic field rotate with the same speed, because the magnetic field is generated through a shaft mounted permanent magnet mechanism and current is induced into the stationary armature.

Synchronous generators are the majority source of commercial electrical energy. They are commonly used to convert the mechanical power output of steam turbines, gas turbines, reciprocating engines and hydro turbines into electrical power for the grid. Some designs of Wind turbines also use this generator type. EE137A HW12. In the majority of designs the rotating assembly in the centre of the generator

the "rotor "contains the magnet, and the "stator" is the stationary armature that is electrically connected to a load. As shown in the diagram, the perpendicular component of the stator field affects the torque while the parallel component affects the voltage. The load supplied by the generator determines the voltage. If the load is inductive, then the angle between the rotor and stator fields will be greater than 90 degrees which corresponds to an increased generator voltage. This is known as an overexcited generator. The opposite is true for a generator supplying a capacitive load which is known as an under excited generator. A set of three conductors make up the armature winding in standard utility equipment, constituting three phases of a power circuit—that correspond to the three wires we are accustomed to see on transmission lines. The phases are wound such that they are 120 degrees apart spatially on the stator, providing for a uniform force or torque on the generator rotor. The uniformity of the torque arises because the magnetic fields resulting from the induced currents in the three conductors of the armature winding combine spatially in such a way as to resemble the magnetic field of a single, rotating magnet. This stator magnetic field or "stator field" appears as a steady rotating field and spins at the same frequency as the rotor when the rotor contains a single dipole magnetic field. The two fields move in "synchronicity" and maintain a fixed position relative to each other as they spin.

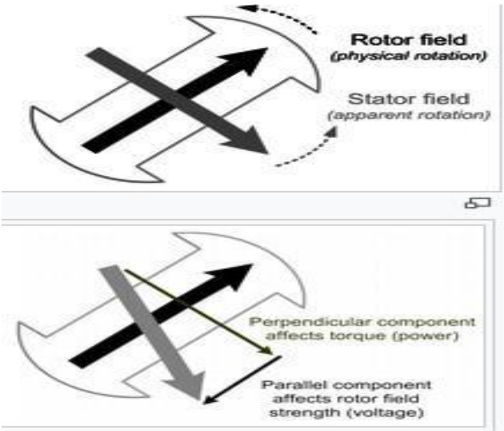

Fig -1: Operation of Synchronous Generator

They are known as synchronous generators because f, the frequency of the induced voltage in the stator (armature conductors) conventionally measured in hertz, is directly proportional to RPM, the rotation rate of the rotor usually given in revolutions per minute (or angular speed). If the rotor windings are arranged in such a way as to produce the effect of more than two magnetic poles, then each physical revolution of the rotor results in more magnetic poles moving past the armature windings. Each passing of a north and South Pole corresponds to a complete "cycle" of a magnet field oscillation. Therefore, the constant of proportionality is where P is the number of magnetic rotor poles (almost always an even number), and the factor of 120 comes from 60 seconds per minute and two poles in a single magnet.

In a permanent magnet generator, the magnetic field of the rotor is produced by permanent magnets. Other types of generators use electromagnets to produce a magnetic field in a rotor winding. The direct current in the rotor field winding is fed through a slip-ring assembly or provided by a brushless exciter on the same shaft. Permanent magnet generators (PMGs) or alternators (PMAs) do not require a DC supply for the excitation circuit, nor do they have slip rings and contact brushes. A key disadvantage in PMAs or PMGs is that the air gap flux is not controllable, so the voltage of the machine cannot be easily regulated. A persistent magnetic field imposes safety issues during assembly, field service or repair. High performance permanent magnets, themselves, have structural and thermal issues. Torque current MMF vectorially combines with the persistent flux of permanent magnets, which leads to higher air-gap flux density and eventually, core saturation. In these permanent magnet alternators, the speed is directly proportional to the output voltage of the alternator.

2.1.2 Pitch Angle Control:

The pitch angle controller used in this paper, employs a PI controller as shown below:

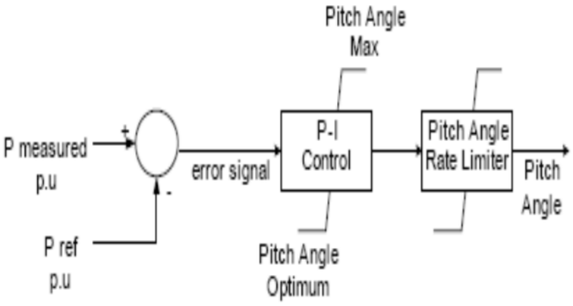

Fig -2: Pitch Controller

As long as the wind turbine output power is lower than the rated power of the wind turbine, the error signal is negative and pitch angle is kept at its optimum value. But once the wind turbine output power exceeds the rated power Pref, the error signal is positive and the pitch angle changes to a new value, at a finite rate, thereby reducing the effective area of the blade resulting in the reduced power output. Inputs to the PI controller are in per-unit and the parameters for the controller are obtained from reference

Wind energy conversion system is consisting of a wind turbine which converts wind energy to mechanical energy. The shaft of the wind turbine is connected to the shaft of the Permanent magnet synchronous generator through a gear box. The gear box provides the rated torque to the generator. The generator develops rated three phase voltages and currents, which are then connected to three-phase converter. The configuration of this WECS is illustrated in Fig-3.

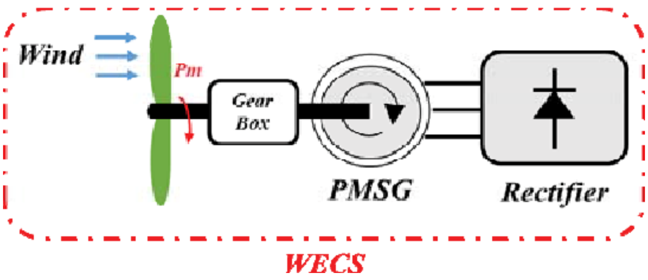

Fig -3: Wind Energy Conversion system

2.2 Shunt Active Power Filter:

The shunt active power filter, the most significant and most extensively used in industrial processes. It is connected to power system in parallel as shown in Figure-4.4.

The advantage of shunt APFs that it only carries the compensation current for compensating system losses and to retain DC voltage constant at the terminals of capacitor with the addition of a small active fundamental current component. Even so, shunt APF can be utilized for compensating reactive power at high voltage distribution as well. This configuration of filter is commonly used to cancel current harmonics fed to the voltage sources. Connecting several active filters in parallel will provide high currents, suitable for loads with high power ratings. However, the impedance of the source side is higher than the impedance of diode rectifier (nonlinear load). Thus, the injected compensating current from the shunt active filter flows together into the source and diode rectifier. As a result of this, shunt active filters may not completely cancel the harmonics, but can increase the DC ripple and the AC peak current of the diode rectifier. A series inductance can be used with shunt APF to avoid these problems.

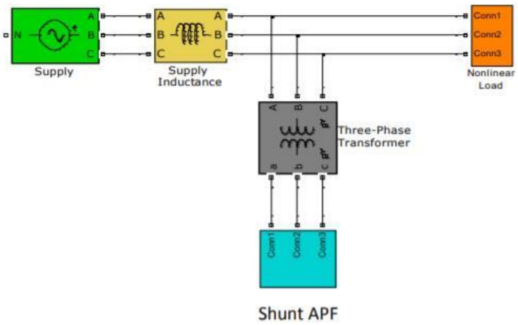

Fig -4: Shunt Active Power Filter

2.3 Basic Direct Power Control Strategy:

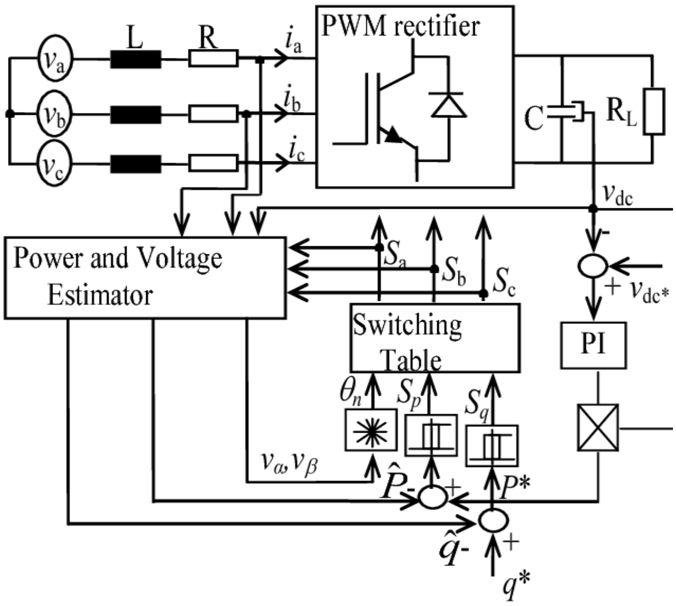

Fig -5: Configuration of Direct Power Control

In this configuration, the dc-bus voltage is regulated by controlling the active power, and the unity power factor operation is achieved by controlling the reactive power to be zero. As shown in Fig.5, the active power command is provided from a dc-bus voltage control block, while the reactive power command is directly given from the outside of the controller. Errors between the commands and the estimated feedback power are input to the hysteresis comparators and digitized to the signals Sp and Sq. Also, the phase of the power-source voltage vector is converted to the digitized signal θ n. For this purpose, the stationary coordinates are divided into 12 sectors, as shown in Fig. 6, and the sectors can be numerically expressed as:

$$(N-2)\frac{\pi}{6} < \theta_N < (N-1)\frac{\pi}{6}$$

Where n=1,2,3,….12

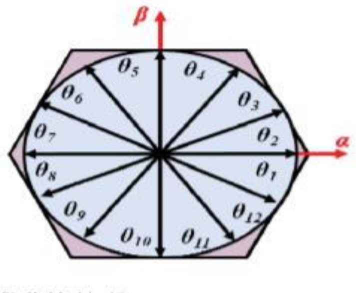

Fig -6: Twelve sectors on stationary coordinates to specify voltage vector phase

By using several comparators, it is possible to specify the sector where the voltage vector exists. The digitized error signals and digitized voltage phase are input to the switching table in which every switching state sp and sq of the converter is stored, as shown in Table 4.1. By using this switching table, the optimum switching state of the converter can be selected uniquely in every specific moment according to the combination of the digitized input signals. The selection of the optimum switching state is performed so that the power errors can be restricted within the hysteresis bands.

S_P	1	1	0	0
S_Q	1	0	1	0
θ_1	101	111	101	100
θ_2	111	111	100	110
θ_3	100	000	100	110
θ_4	000	000	110	010
θ_5	110	111	110	010
θ_6	111	111	010	011
θ_7	010	000	010	011
θ_8	000	000	011	011
θ_9	011	111	011	101
θ_{10}	111	111	001	101
θ_{11}	001	000	001	101
θ_{12}	000	000	101	100

Table 1: Switching table for direct instantaneous power control

In terms of the switching states of the converter, the three phase line currents, the dc-bus voltage, and the inductance of the reactors, the estimated values of p and q and can be derived as:

$$\bar{p} = L\left(\frac{di_a}{dt} i_a + \frac{di_b}{dt} i_b + \frac{di_c}{dt} i_c\right) + V_{DC}\left(s_a i_a + s_b i_b + s_c i_c\right)$$

$$\bar{q} = \frac{1}{\sqrt{3}}\left\{3L\left(\frac{di_a}{dt} i_c - \frac{di_c}{dt} i_a\right) - V_{DC}\left[S_a(i_b - i_c) + S_b(i_c - i_a) + S_c(i_a - i_b)\right]\right\}$$

Supposing practical data processing of the above equations by using microprocessors or digital signal processors (DSP's), differential operations of the currents are performed on the basis of calculus of finite differences. Therefore, it is necessary to suppress steep current ripples due to the converter switching by employing a relatively large inductance and to calculate the finite differences of the currents as accurately as possible. Since the proposed estimation method has been derived throughout by using instantaneous variables, it is possible to estimate harmonic components of the power-source voltages, as well as the fundamental components. This implies that improvement of the total power factor and efficiency taking the harmonics into account can be expected by this method. DPC has following advantages: Simpler voltage and power estimation algorithm, Easy implementation of the unbalanced and distorted line voltage compensation to obtain sinusoidal currents (low THD), excellent dynamics and no coordinate transformation is required.

2.4 WECS Interfaced with Shunt active power filter:

The structure of shunt active power filter interfaced by Wind Energy Conversion System (WECS) is shown in Fig. 4.7. It consists of a permanent magnet synchronous generator (PMSG) based wind turbine connected through a rectifier converter to a three-phase inverter that is connected to a grid through a simple filter and nonlinear load. Whereas the inverter is used to transfer the power from wind turbine, it also assures the compensation of the harmonic currents and reactive power.

Voltage Source Converters Electric power produced by the PMSG is transferred to the power grid through two three-phase full-bridge two-level PWM voltage source converters in the back-to-back configuration with a DC link as shown in Figure 7. The machine-side converter (MSC) operates as a rectifier, whose PWM pulses are provided by the proposed controllers and perform a vector (field-oriented) control of the PMSG. The grid-side converter (GSC) operates as an inverter, whose role is to transfer the energy stored in the DC link to the grid. The GSC controller stabilizes voltage Vdc on the DC link and synchronizes (using the phase-locked loop (PLL)) and controls the GSC output voltages and currents to establish an appropriate grid connection

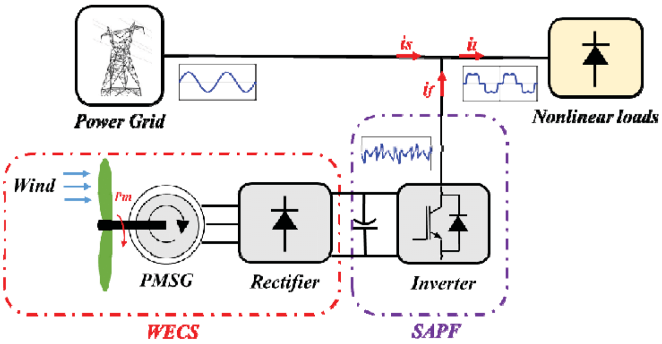

Fig 7: Shunt Active Power Filter Interfaced by Wind Energy Conversion System

3. SIMULATION RESULTS

Simulations of a multifunctional grid-connected inverter interfaced with a wind energy conversion system (WECS) controlled by proposed direct power control have been carried out with Matlab/Simulink software. The system is not only capable of supplying extracted wind power to the power system, but it also can significantly mitigate harmonic currents which are drawn by non-linear loads. The parameters of the system are show in table.

Wind turbine parameters	
Nominal mechanical power	15KW
Base power of generator	15 /0.9 KVA
Base wind speed	12 m/s
Base rotational speed	1pu
Pitch angle	0°
Grid power	
Source Voltage Vs	220 V
Supply frequency fs	50 Hz
Source impedance R_s, L_s	$3.10^{-3}\Omega$, 2.6 μH
SAPF	
Filter impedance R_f, L_f	$10.10^{-3}\Omega$, $0.3.10^{-3}$ H
Line impedance R_l, L_l	$20.10^{-3}\Omega$, 3.10^{-3} H
DC-link voltage reference Vdcref	500V
DC-link capatitor C	2200μF
Diode rectifier load R_L, L_L	20Ω, 2 10^{-3} H

Table 2 : Parameters

The performance of grid connected WECS system, MATLAB simulation results are source voltage, source currents, active, reactive powers and harmonic spectrum without compensation is discussed in Case-A, with PI controllers discussed in Case-B.

3.1 SIMULATION MODEL WITHOUT ASF:

Fig 5.1 shows the simulated PI controller. However, we have built the controlling technique for converter and inverter section, where grid voltage is taken into reference. The variable speed wind generator is considered.

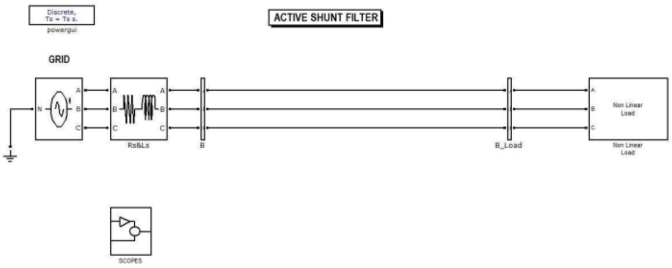

Fig 8 - Simulated WECS without ASF

The fig 8 shows the simulated model for the wind energy conversion system at maximum power point. WECS is fed to the rectifier side and inverter side bus and fed to the non-linear load without ASF in simulation as shown above figure.

The above modelled PMSG is also taken into consideration. Simulated model and the respective output wave forms are presented below.

3.2 SIMULATION MODEL WITH WECS AND APF:

Simulation results after harmonics compensation with and without WECS employing PI controllers is shown figure.5.2. The simulation diagram of WECS with ASF is connected to grid with compensation of active shunt filter.

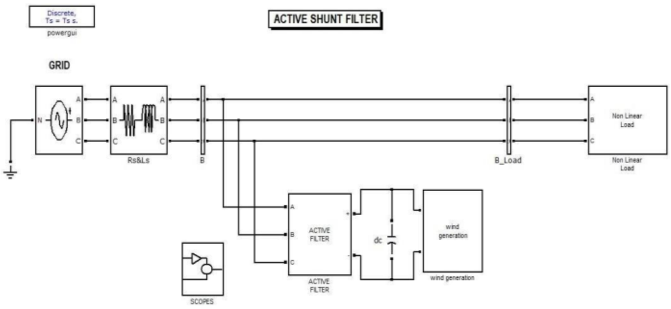

Fig 9: Simulation of WECS With ASF

3.3 Simulation result before harmonics compensation (without ASF):

3.3.1 SOURCE VOLTAGE:

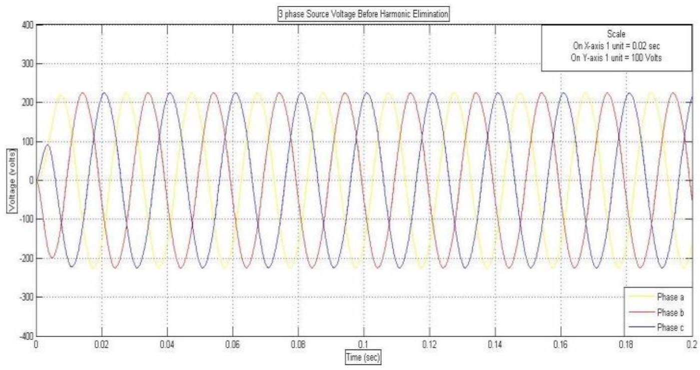

Fig 10: Source voltage without ASF

Figure 10 shows the three-phase source voltage, V_{abc} and its result get between V_{abc} and time and its peak-to-peak voltage is 220V is from 0 to 0.4sec for WECS without compensation of ASF.

3.3.2 SOURCE CURRENT:

Figure 11 shows the three-phase current, I_{abc} and its result get between I_{abc} and time and its peak-to-peak current is 10A from 0 to 0.4sec for WECS without compensation of ASF.

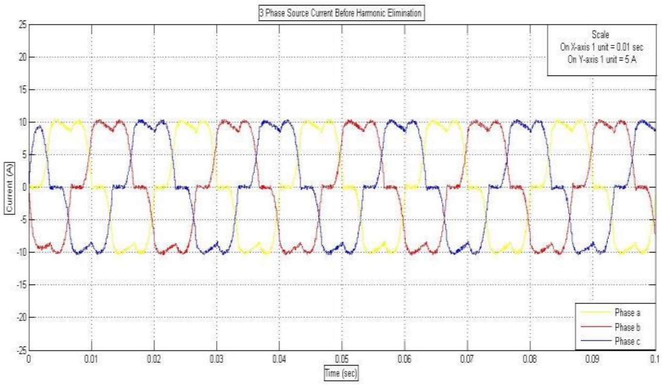

Fig 11: Source voltage without ASF

3.3.3 ACTIVE POWER:

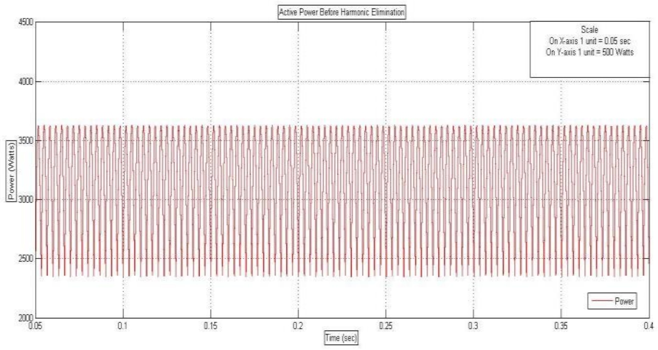

Fig 12: Active Power without ASF

Figure 12 shows the real power, P and it's result get between P and time and its power is 3600w from 0 to 0.4sec for WECS without compensation of ASF.

3.3.4 REACTIVE POWER:

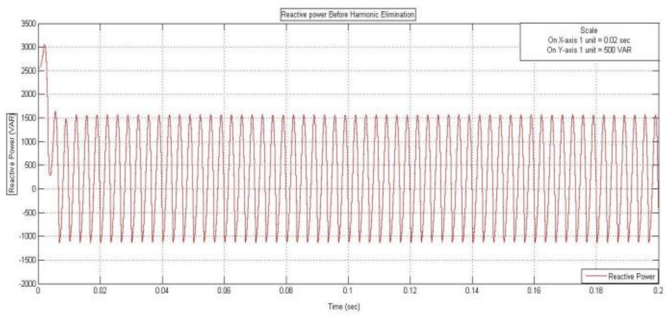

Fig 13: Reactive power without ASF

Figure 13 shows the reactive power, Q and it's result get between Q and time and its reactive power is 1500Var from 0 to 0.4sec for WECS without compensation of ASF.

3.3.5 THD OF SOURCE CURRENT:

From the simulation results in without compensation technique harmonic content in source current is high that is measured in terms of total harmonic distortion (THD) factor that is obtained around 21.11%.

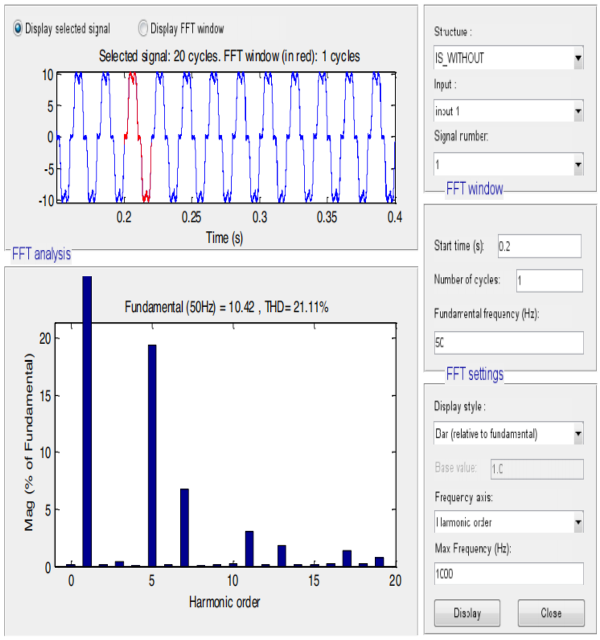

Fig 14: THD of source current without ASF

3.4 Simulation results after harmonics compensation:

3.4.1 SOURCE VOLTAGE:

From the simulation results is clear that harmonics in source current is less. Figure 15 shows the three-phase source voltage, Vabc and its result get between Vabc and time and its peak-to-peak voltage is 220V is from 0 to 0.4sec for WECS with and without compensation of ASF.

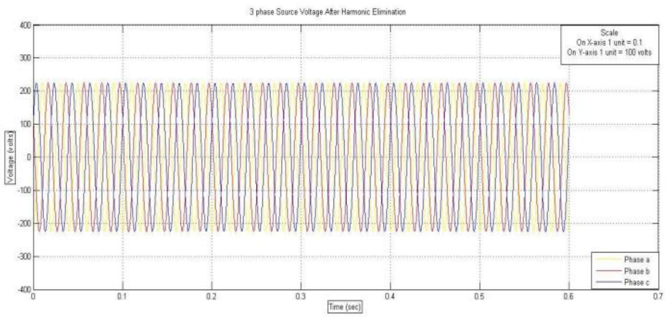

Fig 15: Source voltage with ASF

3.4.2 SOURCE CURRENT:

Figure 16 shows the three-phase current, Iabc and it's result get between Iabc and time and its peak-to-peak current is 40A at 0.05sec and then 25A constant from 0.1sec to 0.3sec without compensation of ASF, at 0.3sec ASF is compensated 25A to 10A from 0.3 to 0.4sec for WECS connected to grid with non-linear load.

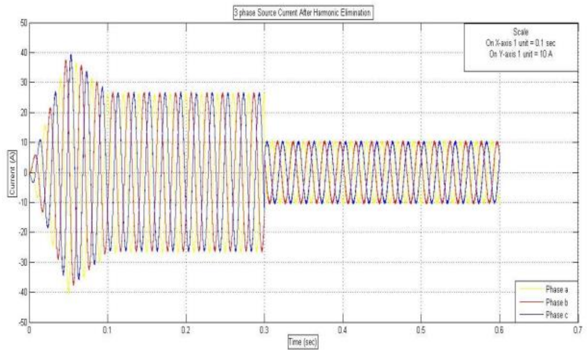

Fig 16: Source Current with ASF

3.4.3 ACTIVE POWER:

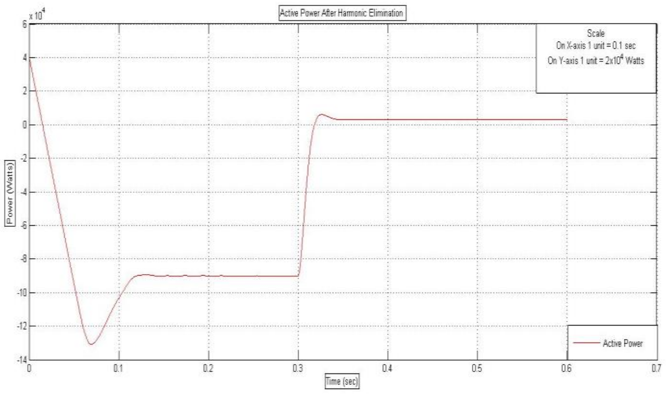

Fig 17: Active Power with ASF

Figure 17 shows the real power, P and its result get between P and time, real power is oscillating from 0sec to 0.11sec. P is constant -9kw from 0.11 sec to0.3 sec without compensation of ASF.

P is raised from 0.3sec to 0.32 sec is from -9w to 0.5kw and then constant from 0.32ssec to 0.6sec with the compensation of ASF for WECS.

3.4.4 REACTIVE POWER:

Figure 18 shows the reactive power, Q and it's result get between Q and time, reactive power is oscillate from 0sec to 0.1sec and then constant from 0.1sec to 0.3sec is 300Var. Q is reduced at 0.3sec is 250Var from 0.3ssec to 0.6sec with the compensation of ASF for WECS.

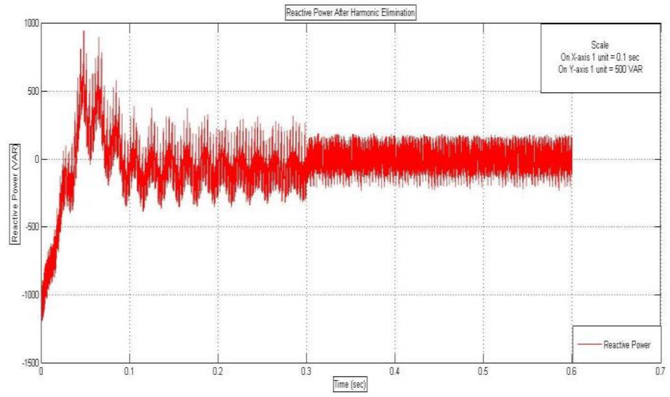

Fig 18: Reactive power with ASF

3.4.5 CURRENT VS VOLTAGE:

From figure 19 we can observe from 0s-0.3s, the opposite phase between voltage and current source and the negative sign of the utility active power (Ps), meaning the filter current has information of harmonic and wind turbine currents to ensure elimination of harmonic and injection of current to the load.

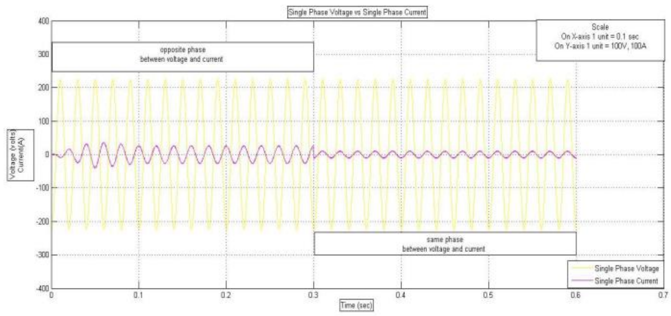

Fig 19: Single Phase Voltage vs Single Phase Current

3.4.6 FILTER CURRENT:

Figure 20 shows the filter current is 30A from 0sec to 0.3sec is constant without compensation of ASF where WECS will inject current opposite to the harmonic current. At 0.3sec with the compensation of ASF for WECS the filter current will inject current opposite to harmonic component of source current

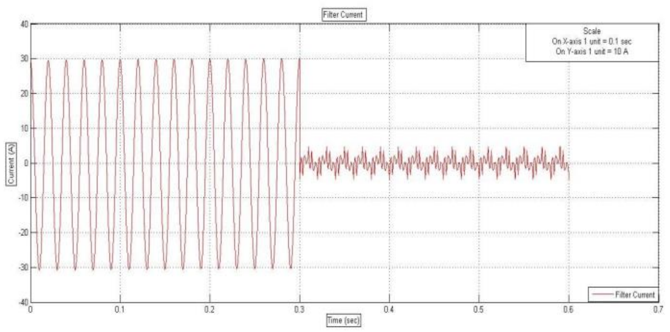

Fig 20: Filter current with ASF

3.4.7 DC LINK VOLTAGE:

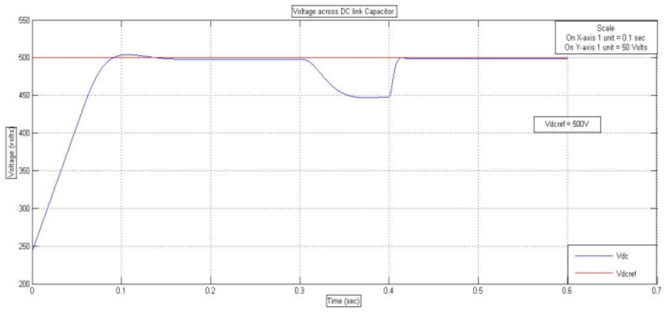

Fig 21: DC Link Voltage

Figure 21 shows the DC link Voltage and DC reference voltage, from 0-0.1 sec the DC link capacitor gets charged to 500V from WECS. It is reduced at 0.3sec is from 500V to 450V with the compensation of ASF and WECS. The dc link voltage returns to its reference value in few milliseconds

3.4.8 THD OF SOURCE CURRENT:

From the THD spectrum it is clear that harmonics production in source is current is 1.59% it is 20 times less than without harmonic compensation technique.

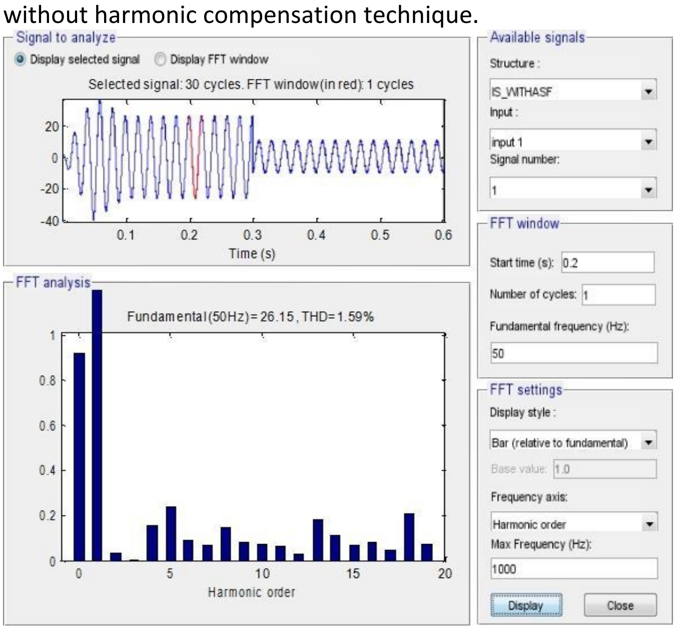

Fig 22: THD of source current with ASF

4. CONCLUSION:

This Journal focused on applying direct power control to a three-phase multifunctional grid- connected inverter interfaced with a wind energy conversion system. The proposed control scheme is used in order to achieve harmonics elimination, reactive power compensation, and simultaneously inject the active power available from the PMSG wind turbine into the load and/or grid. The analysis

of the simulation results obtained has attested the robustness, the effectiveness and the good performance of proposed system. The DPC method has very good performance in injection of active power produced by PMSG wind turbine to the distribution networks and simultaneously compensating harmonics and reactive power.

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REFERENCES

[1] G. Shafiullah, A. MT Oo, A. Shawkat Ali, and P. Wolfs, "Potential challenges of integrating large-scale wind energy into the power grid–A review," Renewable and Sustainable Energy Reviews, vol. 20, pp. 306-321, 2013.
[2] Z. Ming, H. Lixin, Y. Fan, and J. Danwei, "Notice of Retraction Research of the Problems of Renewable Energy Orderly Combined to the Grid in Smart Grid," in Power and Energy Engineering Conference (APPEEC), 2010 Asia Pacific, 2010, pp. 1-4.
[3] P. Cartwright, "Connecting renewables: the challenge of integrating large offshore wind farms," Refocus, vol. 7, pp. 24-26, 2006.
[4] G. Singh, A. Singh, and R. Mitra, "A simple fuzzy logic based robust active power filter for harmonics minimization under random load variation," Electric power systems research, vol. 77, pp. 1101-1111, 2007.
[5] J. S. Subjak Jr and J. S. Mcquilkin, "Harmonics-causes, effects, measurements, and analysis: an update," Industry Applications, IEEE Transactions on, vol. 26, pp. 1034-1042, 1990.

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