

PMSM Drive Based D-STATCOM in Combination with Renewable Energy Sources to Enhance Power Quality

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Abstract - In this concept Fossil fuels are non renewable and environmentally damaging. Due to increasing air pollution, global warming concerns, diminishing fossil fuels and their increasing cost have made it necessary to look towards renewable sources as a future energy solution. There are many Renewable Energy Sources (RES) such as wind, solar, tidal power, biomass etc. Solar energy has great potential to supply energy with minimum impact on the environment, since it is clean and pollution free. In finding solutions to overcome a global energy crisis, the Photo Voltaic (PV) system has attracted significant attention in recent years. The extensive use of these non-linear loads causes harmonic injection into the system which affects the quality of the power supply. These harmonics current causes problems like equipment overheating, supplementary losses, EMI related issues and damage devices etc. Harmonics are introduced into the system by diode or thyristor loads. These harmonics are to be filtered to make the system behavior as per the proposed operation. The power quality problems like current harmonics, current unbalance due to unbalanced and non linear load connected to the PCC is compensated effectively by using shunt active power filter (APF). The hysteresis current controller is used to generate the switching pulses for the gate drives of grid interfacing inverter. The total harmonic distortion (THDs) of the source currents are reduced by using shunt active power filter (APF). The THDs of the distribution system with and without APF are compared. The PMSM motors are a type of synchronous motor this means the magnetic field generated by the stator and the magnetic fields generated by the rotor rotate at the same frequency there are two types of stator windings variants: trapezoidal and sinusoidal motors. This differentiation is made on the basis of the interconnection of coils in the stator windings to give the different types of back Electromotive Force (EMF). The speed of the PMSM motor is controlled by varying the dc bus voltage of the voltage source inverter (VSI) feeding the PMSM motor via a PFC converter. Therefore, the PMSM motor is electronically commutated such that the VSI operates in fundamental frequency switching for reduced switching losses. The whole work is been done in MATLAB/SIMULINK.

Keywords - Diesel Generator, D-STATCOM, MPPT, Power Quality, hysteresis current controller (HCC), total harmonic distortion (THD), Wind Generating System (WGS).

I. INTRODUCTION

Renewable Energy Sources are those energy sources which are not destroyed when their energy is harnessed. Human use of renewable energy requires technologies that harness natural phenomena, such as sunlight, wind, waves, water flow, and biological processes such as anaerobic digestion, biological hydrogen production and geothermal heat. Amongst the above mentioned sources of energy there has been a lot of development in the technology for harnessing energy from the wind. Wind is

the motion of air masses produced by the irregular heating of the earth's surface by sun [1]. These differences consequently create forces that push air masses around for balancing the global temperature or, on a much smaller scale, the temperature between land and sea or between mountains. Wind energy is not a constant source of energy [2]. It varies continuously and gives energy in sudden bursts.

Recently, wind power generation has attracted special interest, and many wind power stations are in service throughout the world. In wind power stations, induction machines are often used as generators, but the development of new permanent magnet generators, the improvement of the AC-DC-AC conversion and its advantages for output power quality make other solutions possible [3]. A recent solution is to use a permanent magnet synchronous generator with variable speed and a conversion stage, which is studied in this paper.

Most of the more important international standards define power quality as the physical characteristics of the electrical supply provided under normal operating conditions that do not disrupt or disturb the customer's processes. Therefore, a power quality problem exists if any voltage, current or frequency deviation results in a failure or in a bad operation of customer's equipment. However, it is important to notice that the quality of power supply implies basically voltage quality and supply reliability. Voltage quality problems relate to any failure of equipment due to deviations of the line voltage from its nominal characteristics, and the supply reliability is characterized by its adequacy (ability to supply the load), security (ability to withstand sudden disturbances such as system faults) and availability (focusing especially on long interruptions) [4-5].

Power quality problems are common in most of commercial, industrial and utility networks. Natural phenomena, such as lightning are the most frequent cause of power quality problems. Switching phenomena resulting in oscillatory transients in the electrical supply, for example when capacitors are switched, also contribute substantially to power quality disturbances. Also, the connection of high power non-linear loads contributes to the generation of current and voltage harmonic

components. Between the different voltage disturbances that can be produced, the most significant and critical power quality problems are voltage sags due to the high economical losses that can be generated. Short term voltage drops (sags) can trip electrical drives or more sensitive equipment, leading to costly interruptions of production [6]. For all these reasons, from the consumer point of view, power quality issues will become an increasingly important factor to consider in order to satisfy good productivity. On the other hand, for the electrical supply industry, the quality of power delivered will be one of the distinguishing factors for ensuring customer loyalty in this very competitive and deregulated market [7]. To address the needs of energy consumers trying to improve productivity through the reduction of power quality related process stoppages and energy suppliers trying to maximize operating profits while keeping customers satisfied with supply quality, innovative technology provides the key to cost-effective power quality enhancements solutions [8]. However, with the various power quality solutions available, the obvious question for a consumer or utility facing a particular power quality problem is which equipment provides the better solution [9].

II. Principle of D-STATCOM

A D-STATCOM is a controlled reactive source, which includes a Voltage Source Converter and a DC link capacitor connected in shunt, capable of generating and/or absorbing reactive power. The operating principles of DSTATCOM are based on the exact equivalence of the conventional rotating synchronous compensator.

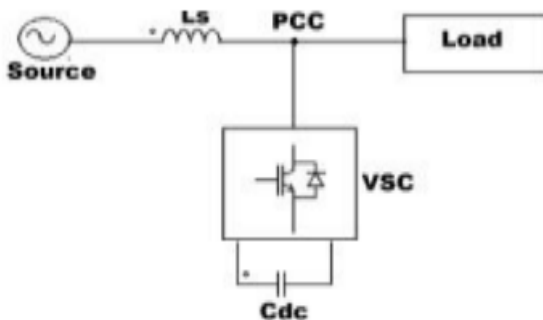


Fig.1. Circuit Diagram of D-STATCOM.

The AC terminals of the VSC are connected to the Point of Common Coupling (PCC) through an inductance, which could be a filter inductance or the leakage inductance of the coupling transformer, as shown in Fig. 1. The DC side of the converter is connected to a DC capacitor, which carries the input ripple current of the converter and is the main reactive energy storage element. This capacitor could be charged by a battery source, or

could be recharged by the converter itself. If the output voltage of the VSC is equal to the AC terminal voltage, no reactive power is delivered to the system. If the output voltage is greater than the AC terminal voltage, the DSTATCOM is in the capacitive mode of operation and vice versa. The quantity of reactive power flow is proportional to the difference in the two voltages. For a DSTATCOM used for voltage regulation at the PCC, the compensation should be such that the supply currents should lead the supply voltages; whereas, for power factor Correction, the supply current should be in phase with the supply voltages. The control strategies studied in this paper are applied with a view to studying the performance of a D-STATCOM for power factor correction and harmonic mitigation.

III. SYSTEM DESCRIPTION

The above system consists of a photovoltaic cell as a RES connected to the dc-link of a grid interfacing inverter as shown in Fig.2. The voltage source inverter (VSI) interfaces the renewable energy source to the grid and delivers the generated power.

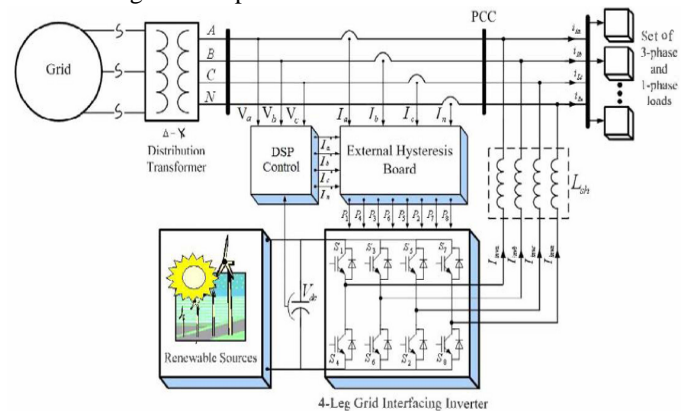


Fig.2. Schematic diagram of renewable based distribution system.

A. Photovoltaic Energy Panel

PV cell is an energy conversion device, which is used to convert the solar energy into an electrical energy and the amount of electrical energy produced depends upon solar irradiation and temperature.

B. Voltage Source Current Controlled Interfacing Inverter

A voltage source current inverter is a power electronic device which is connected in shunt with the system. The function of this inverter is to convert the dc voltage into a balanced three phase ac voltage. If the inverter output voltage is greater than the existing system voltage then the inverter acts in capacitive mode. The switching device used in this voltage source inverter is an IGBT.

C. Control Technique for Grid Interfacing Inverter as Shunt Active power filter

The turn ON and turn OFF instants of the inverter switches should be such that the load and the connected RES could be appeared as a balanced load to the system. For this type of control, we need to monitor the output of dc link capacitor continuously and is compared with the reference voltage V_{dc}^* . The difference between the reference and actual voltages will go through a voltage regulator, whose final output gives an active current component I_m . By multiplying this peak value (I_m) with three unit sine vectors (U_a , U_b and U_c) which are in phase with the three source voltages will generate the reference current (I_a^* , I_b^* and I_c^*). The reference grid neutral current (I_n^*) is set to zero being the instantaneous sum of balanced grid currents. The synchronizing angle (θ) obtained from phase locked loop (PLL) [1] is used to generate unity vector template as

$$U_a = \sin(\theta) \quad (1)$$

$$U_b = \sin(\theta - \frac{2\pi}{3}) \quad (2)$$

$$U_c = \sin(\theta + \frac{2\pi}{3}) \quad (3)$$

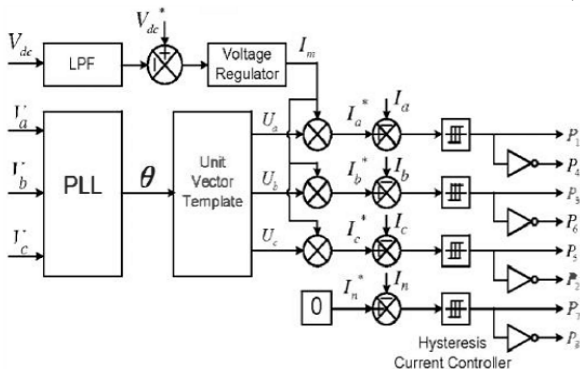


Fig.3. Block diagram of grid interfacing inverter control.

The reference grid currents of the three phase system is given as

$$I_a^* = I_m * U_a \quad (4)$$

$$I_b^* = I_m * U_b \quad (5)$$

$$I_c^* = I_m * U_c \quad (6)$$

The neutral current is taken as

$$I_n^* = 0 \quad (7)$$

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 error as

$$I_{aerr} = I_a^* - I_a \quad (8)$$

$$I_{berr} = I_b^* - I_b \quad (9)$$

$$I_{cerr} = I_c^* - I_c \quad (10)$$

D. Hysteresis Current Control

In this work, the hysteresis current control operation is used to control the operation of the VSI. The gate control signals for the grid interfacing inverter to act as a shunt active filter for compensating current harmonics is given by hysteresis current control signals.

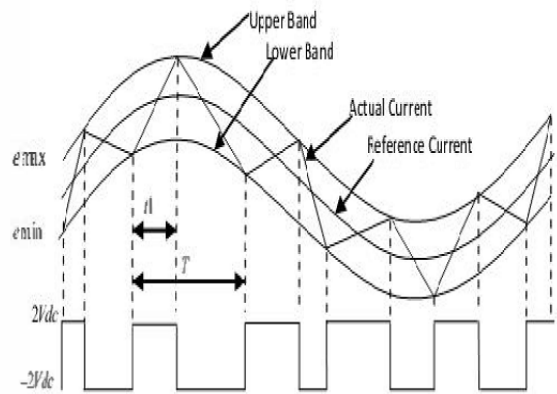


Fig.4. Waveform of Hysteresis Current Control.

An error signal I_{aerr} is used to control the switches in a voltage source inverter. The difference between the desired current I_a^* and the current being injected by the inverter I_a is taken as error. If the error exceeds the upper limit of the band, the upper switch of the inverter is turned OFF and the lower switch is turned ON, which implies that the current starts decreasing. If the error crosses the lower limit of the band, the lower switch of the inverter is turned OFF and the upper switch is turned ON, which implies that the current starts increasing and gets back into the band. The upper and maximum values of the error signal are e_{min} and e_{max} respectively. The range of the error signal is $e_{max} - e_{min}$ directly controls the amount of ripple content in the current output from VSI.

IV. Hysteresis current control

Hysteresis band PWM control is basically an instantaneous feedback current control method of PWM, where the actual current continuously tracks the command current within a hysteresis band. A reference sine wave current wave is compared with the actual phase current wave. When the current exceeds a prescribed hysteresis band, the upper switch in the inverter bridge is turned off

and the lower switch is turned on, and the current starts to decay. As the current crosses the lower band limit, the lower switch is turned off and the upper switch is turned on. The actual current is forced to track the sine reference within the hysteresis band by back and forth (or bang-bang) switching of the upper and lower switches. The inverter then essentially becomes a current source with peak-to-peak current ripple, which is controlled within the hysteresis band, which makes the source current to be sinusoidal.

The switching logic is realized by three hysteresis controllers, one for each phase (figure.5). The hysteresis PWM current control, also known as “bang-bang” control, is done in the three phases separately. Each controller determines the switching -state of one inverter half-bridge in such a way that the corresponding current is maintained within a hysteresis band.

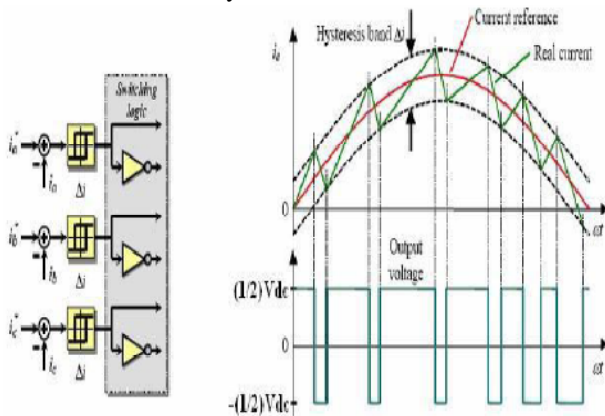


Fig.5. Hysteresis PWM Current Control and Switching Logic.

To increase a phase current, the affiliated phase to neutral voltage is equal to the half dc bus voltage until the upper band-range is reached. Then, the negative dc bus voltage $-\frac{1}{2}U_{dc}$ applied as long as the lower limit is reached &c. More complicated hysteresis PWM current control techniques also exist in practice, e.g. adaptive hysteresis current vector control is based on controlling the current phasor in a $\alpha\beta$ -reference frame. These modified techniques take care especially for the interaction of the three phases. Obviously, the dynamic performance of such an approach is excellent since the maximum voltage is applied until the current error is within predetermined boundaries (bang-bang control). Due to the elimination of an additional current controller, the motor parameter dependence is vastly reduced. However, there are some inherent drawbacks.

- No fixed PWM frequency: The hysteresis controller generates involuntary lower sub harmonics.
- The current error is not strictly limited. The signal may leave the hysteresis band caused by the voltage of the other two phases.

- Usually, there is no interaction between the three phases: No strategy to generate zero-voltage phasors.
- Increased switching frequency (losses) especially at lower modulation or motor speed.
- Phase lag of the fundamental current (increasing with the frequency).

Hysteresis current control is used for operation at higher switching frequency, as this compensates for their inferior quality of modulation. The switching losses restrict its application to lower power levels. Due to the independence of motor parameters, hysteresis current control is often preferred for stepper motors and other variable-reluctance motors. A carrier-based modulation technique, as described in the next subsection, eliminates the basic shortcomings of the hysteresis PWM controller. However, when being compared to the hysteresis PWM, an additional current control loop, calculating the reference voltages, is required when subsequent modulation schemes are applied to high-performance motion control systems.

V. WIND ENERGY BASED SYSTEM

Wind is abundant almost in any part of the world. Its existence in nature caused by uneven heating on the surface of the earth as well as the earth’s rotation means that the wind resources will always be available. The conventional ways of generating electricity using non renewable resources such as coal, natural gas, oil and so on, have great impacts on the environment as it contributes vast quantities of carbon dioxide to the earth’s atmosphere which in turn will cause the temperature of the earth’s surface to increase, known as the green house effect. Hence, with the advances in science and technology, ways of generating electricity using renewable energy resources such as the wind are developed. Nowadays, the cost of wind power that is connected to the grid is as cheap as the cost of generating electricity using coal and oil. Thus, the increasing popularity of green electricity means the demand of electricity produced by using non renewable energy is also increased accordingly.

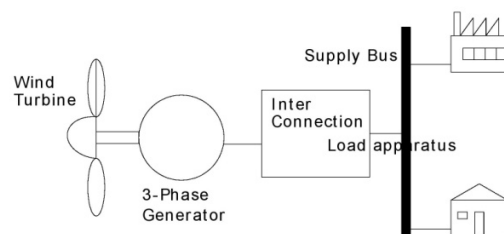
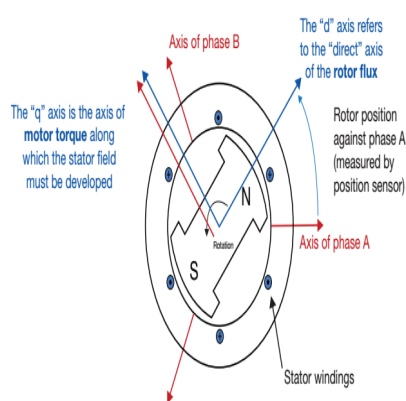


Fig.6. Structure of a typical wind energy system.

The major components of a typical wind energy conversion system include a wind turbine, generator, interconnection apparatus and control systems, as shown in Figure 6. Wind turbines can be classified into the vertical axis type and the horizontal axis type. Most modern wind turbines use a horizontal axis configuration with two or three blades, operating either down-wind or up-wind. A wind turbine can be designed for a constant speed or variable speed operation generator is coupled to the rotor of a wind turbine directly, offers high reliability, low maintenance, and possibly low cost for certain turbines, power electronic converters to provide a fixed frequency and fixed voltage power to their loads.

Permanent magnet synchronous motors (PMSM)

Permanent magnet synchronous motors (PMSM) are typically used for high-performance and high-efficiency motor drives. High-performance motor control is characterized by smooth rotation over the entire speed range of the motor, full torque control at zero speed, and fast acceleration and deceleration. To achieve such control, vector control techniques are used for PM synchronous motors. The vector control techniques are usually also referred to as field-oriented control (FOC). The basic idea of the vector control algorithm is to decompose a stator current into a magnetic field-generating part and a torque generating part. Both components can be controlled separately after decomposition. Then, the structure of the motor controller (vector control controller) is almost the same as a separately excited DC motor, which simplifies the control of a permanent magnet synchronous motor. Let's start with some basic FOC principles.



Torque Generation

A reactance torque of PMSM is generated by an interaction of two magnetic fields (one on the stator and one on the rotor). The stator magnetic field is represented by the magnetic flux/stator current. The magnetic field of

the rotor is represented by the magnetic flux of permanent magnets that is constant, except for the field weakening operation. We can imagine those two magnetic fields as two bar magnets, as we know a force, which tries to attract/repel those magnets, is maximal, when they are perpendicular to each other. It means that we want to control stator current in such a way that creates a stator vector perpendicular to rotor magnets. As the rotor spins we must update the stator currents to keep the stator flux vector at 90 degrees to rotor magnets at all times. The reactance torque of an interior PM type PMSM (IPMSM) is as follows, when stator and rotor magnetic fields are perpendicular. $Torque = 32ppI_{PM}I_{qs}$ pp – Number of pole pairs I_{PM} – Magnetic flux of the permanent magnets I_{qs} – Amplitude of the current in quadrature axis As shown in the previous equation, reactance torque is proportional to the amplitude of the q-axis current, when magnetic fields are perpendicular. MCUs must regulate the phase stator current magnitude and at the same time in phase/angle, which is not such an easy task as DC motor control.

How to Simplify Control of Phase Currents to Achieve Maximum Torque

DC motor control is simple because all controlled quantities are DC values in a steady state and current phase/ angle is controlled by a mechanical commutator. How can we achieve that in PMSM control? DC Values/Angle Control First, we need to know the rotor position. The position is typically related to phase A. We can use an absolute position sensor (e.g., resolver) or a relative position sensor (e.g., encoder) and process called alignment. During the alignment, the rotor is aligned with phase A and we know that phase A is aligned with the direct (flux producing) axis. In this state, the rotor position is set to zero (required voltage in d-axis and rotor position is set to zero, static voltage vector, which causes that rotor attracted by stator magnetic field and to align with them [with direct axis]).

- 1 Three-phase quantities can transform into equivalent two-phase quantities (stationary reference frame) by Clarke transformation.
2. Then, we transform two-phase quantities into DC quantities by rotor electrical position into DC values (rotating reference frame) by Park transformation. The electrical rotor position is a mechanical rotor position divided by numbers of magnetic pole pairs pp . After a control process we should generate three-phase AC voltages on motor terminals, so DC values of the required/generated voltage should be transformed by inverse Park/Clarke transformations.

VI.MATLAB/SIMULATION RESULTS

A. Balanced Nonlinear Load

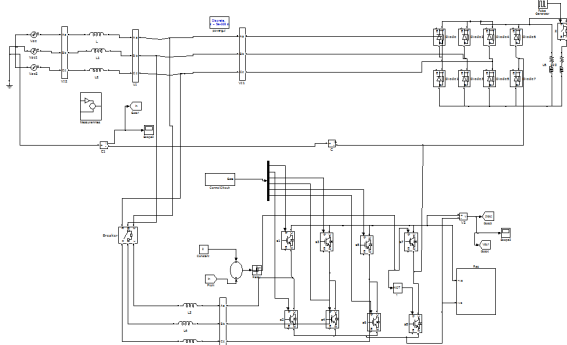


Fig.7. Matlab/Simulink Model of balanced non-linear load.

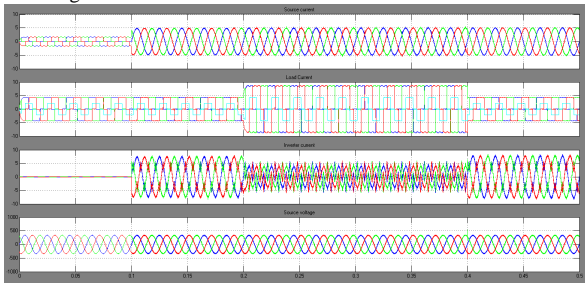


Fig.8. Simulation results of Balanced Non-linear Load Source current, Load current, Inverter current and source voltage.

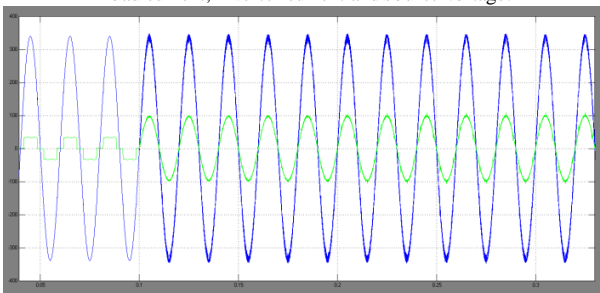


Fig.9. source voltage and current.

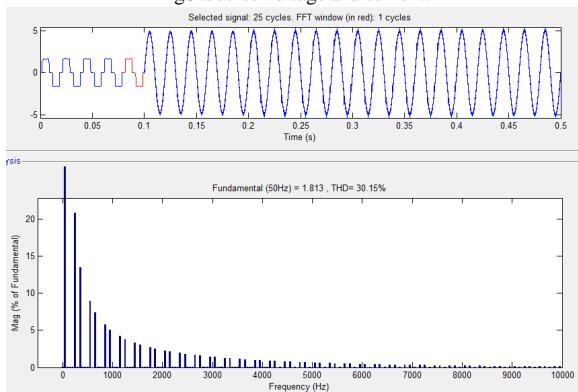


Fig.10. THD of source current before compensation.

The source current of balanced Non-linear load before compensation is 30.15%.

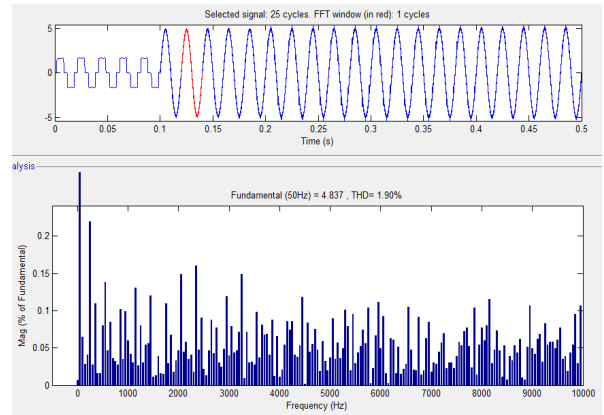


Fig.11. THD of source current after compensation.

The source current of balanced Non-linear load after compensation is 1.90%.

B. Unbalanced Non-linear Load

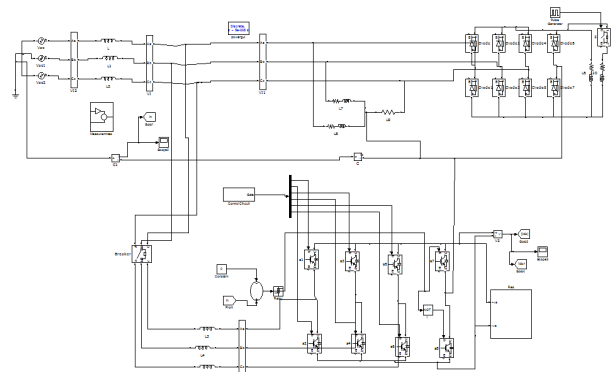


Fig.12. Matlab/Simulink Model of unbalanced non-linear load.

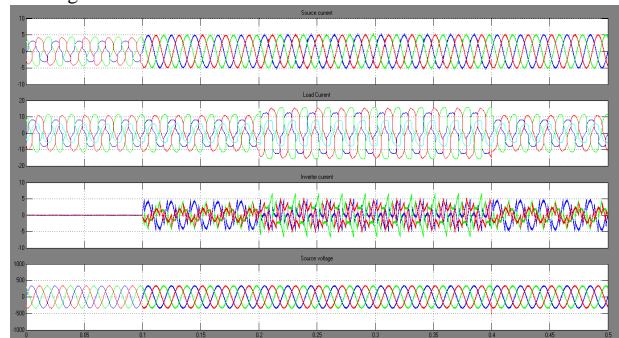


Fig.13. Simulation results of unbalanced Non-linear Load Source current, Load current, Inverter current and source voltage.

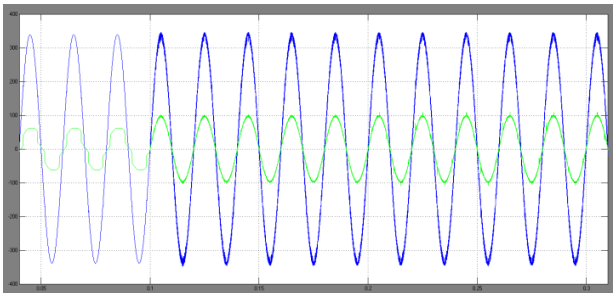


Fig.14.source voltage and current.

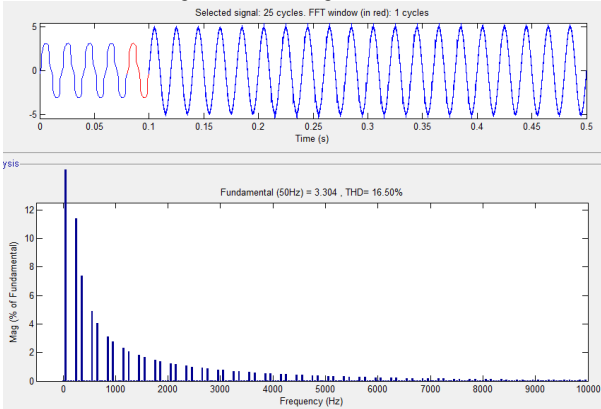


Fig.15. THD of source current before compensation.

The source current of unbalanced non-linear load before compensation is 16.50%

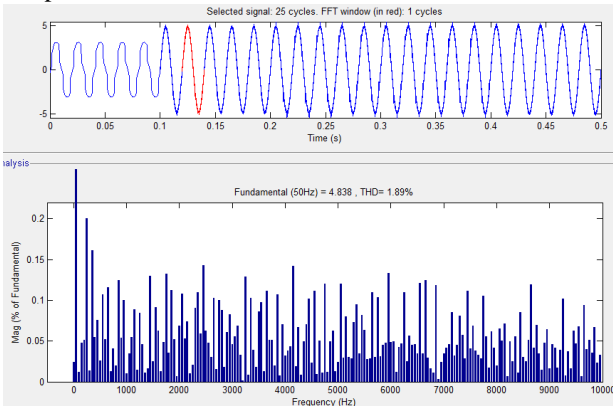


Fig.16. THD of source current after compensation.

The source current of unbalanced non-linear load after compensation is 1.89%

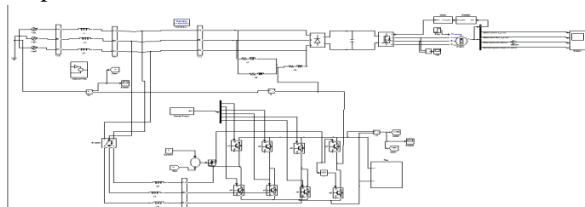


Fig 17 Matlab/Simulink Model of balanced non-linear load with PMSM motor

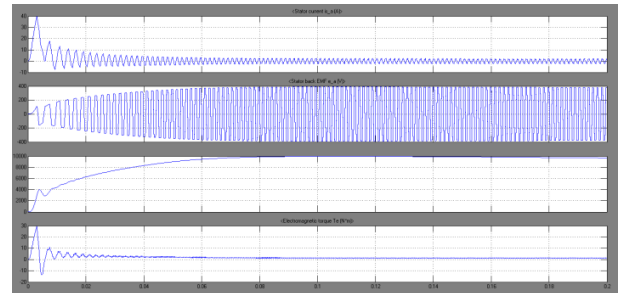


Fig 18 simulation wave form of PMSM motor drive stator current, EMF, speed and torque

VII. CONCLUSION

To carry out any investigation in the power quality improvement it needs a thorough knowledge of nature of the power quality issues over the particular location of transmission lines and complete understanding of FACTS devices and controllers. In this work, a fast and cost effective D-STATCOM is proposed for reducing the problem of harmonics in industrial distribution systems. Hysteresis loss current control algorithm utilizes the error signal which is the difference between the reference voltage and actual measured load voltage to trigger the switches of an inverter using a Pulse Width Modulation (PWM) scheme. The D-STATCOM handled the situation without any difficulties and injected the appropriate voltage component to correct rapidly any changes in the supply voltage there by keeping the load voltage balanced and constant at the nominal value. The performance of a shunt active filter is studied by using multi-function grid interfacing inverter under various load conditions. The power quality problems like current harmonics, current unbalance due to unbalanced and non linear load connected to the PCC is compensated effectively by using shunt active power filter (APF). The hysteresis current controller is used to generate the switching pulses for the gate drives of grid interfacing inverter. The proposed scheme is superior compared to the other conventional controller technique in terms of energy saving and dynamic performance. The PQ theory control with hysteresis loss current control algorithm based D-STATCOM has the ability for good compensation characteristics. By using this compensation strategy the THD (Total Harmonics Distortion) is reduced up to 1.89%. and to connected to PMSM motor drive and study the characteristics of motor

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