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Improved Power Quality by using STATCOM Under Various Loading Conditions

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ABSTRACT

A Power quality problem is an occurrence manifested as a nonstandard voltage, current or frequency that results in a failure or a mis-operation of end user equipment's. Utility distribution networks, sensitive industrial loads and critical commercial operations suffer from various types of outages and service interruptions which can cost significant financial losses. With the restructuring of power systems and with shifting trend towards distributed and dispersed generation, the issue of power quality is going to take newer dimensions. Injection of the wind power into an electric grid affects the power quality. The performance of the wind turbine and thereby power quality are determined on the basis of measurements and the norms followed according to the guideline specified in International Electro-technical Commission standard, IEC-61400. The influence of the wind turbine in the grid system concerning the power quality measurements are-the active power, reactive power, variation of voltage, flicker, harmonics, and electrical behavior of switching operation and these are measured according to national/international guidelines. Static Compensator (STATCOM) is connected at a point of common coupling with a battery energy storage system (BESS) to mitigate the power quality issues. The battery energy storage is integrated to sustain the real power source under fluctuating wind power. Here two control schemes for STATCOM are Fuzzy logic controller and hybrid Fuzzy logic controller. We can better response for hybrid fuzzy compare to fuzzy logic controller. The STATCOM control scheme for the grid connected wind energy generation system for power quality improvement is simulated using MATLAB/SIMULINK in power system block set. Finally the proposed scheme is applied for both balanced and unbalanced linear nonlinear loads.

KEYWORDS: *STATCOM, power quality, wind generating system, Battery Energy Storage System (BESS), Bang –Bang current controller, Fuzzy logic controller.*

I. INTRODUCTION

Electric Power quality is a term which has captured increasing attention in power engineering in the recent years. Even though this subject has always been of interest to power engineers, it has assumed considerable interest in the 1990's. Electric power quality means different things for different people. To most electric power engineers, the term refers to a certain sufficiently high grade of electric service but beyond that there is no universal agreement [1-3]. The measure of power quality depends upon the needs of the equipment that is being supplied. What is good power quality for an electric motor may not be good enough for a personal computer. Usually the term power quality refers to maintaining a sinusoidal waveform of bus voltages at rated voltage and Frequency [4].

The waveform of electric power at generation stage is purely sinusoidal and free from any distortion. Many of the Power conversion and consumption equipment are also designed to function under pure sinusoidal voltage waveforms. However, there are many devices that distort the waveform. These distortions may propagate all over the electrical network. In recent years, there has been an increased use of non-linear loads which has resulted in an increased fraction of non-sinusoidal currents and voltages in Electric Network. Classification of power quality areas may be made according to the source of the problem such as converters, magnetic circuit non linearity, arc furnace or by the wave shape of the signal such as harmonics, flicker or by the frequency spectrum (radio frequency interference) [5-8].

The wind turbines (WTs) considered in this thesis are Doubly Fed Induction Generators (DFIGs) that are capable of variable speed operation. A DFIG has a power electronic converter by which both real power and reactive power can be controlled. A STATCOM was employed to regulate the voltage at the bus, to help maintain constant DC link voltages at individual wind turbine inverters during disturbances [9]. This feature will facilitate the continuous operation of each individual wind turbine during disturbances, thus enabling the wind farm to participate in the grid side voltage and power control.

The dynamic DFIG model available in Dig SILENT Power Factory Version 13.2 [10] was used for the simulations. The STATCOM with a higher rating capacity was developed based on the study of an available low capacity STATCOM model. The complete power grid studied in this thesis is a combined case study of interconnected two wind turbines, a synchronous generator, a STATCOM and a typical load all forming a four bus system. Power control [11].

II. Topology for Power Quality Improvement

The STATCOM is a three- phase voltage source inverter having the capacitance on its DC link and connected at the point of common coupling. The STATCOM injects a compensating current of variable magnitude and frequency component at the bus of common coupling [1]. Here the utility source, wind energy system and STATCOM with BESS are connected to the grid. The current controlled voltage source inverter based STATCOM injects the current into the grid in such a way that the source current (grid current) are harmonic free and they are in phase-angle with respect to source voltage. The injected current will cancel out the reactive part and harmonic part of the induction generator current and load current, thus it improves the power quality [4]. This injected current generation is by proper closing and opening of the switches of voltage source inverter of STATCOM and is different for the two control schemes proposed. For this the grid voltages are sensed and are synchronized in generating the current command for the inverter.

A. Wind Energy Generating System

In this configuration, wind energy generation is based on constant speed topologies with pitch control turbine.

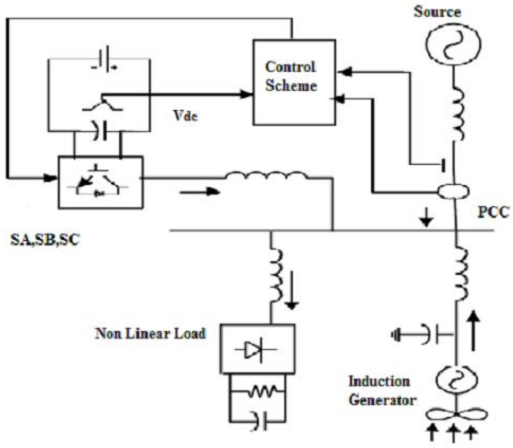

Fig.1.System operational scheme in grid system.

The induction generator is used in the proposed scheme because of its simplicity, it does not require a separate field circuit, it can accept constant and variable loads, and has natural protection against short circuit. The available power of wind energy system is presented as:

$$P_{wind} = \frac{1}{2} \rho A \bar{V}_{wind}^{3} \quad (1)$$

Where ρ= air density (kg/m3), A = area swept out by turbine blade (m), V wind= wind speed (m/s). It is not possible to extract all kinetic energy of wind. Thus extracts a fraction of the power called power coefficient 'Cp' of the wind turbine, and is given by:-

$$P_{mech} = C_p P_{wind} \quad (2)$$

The mechanical power produced by wind turbine is given by:-

$$P_{mech} = \frac{1}{2} \rho \Pi R^2 V_{wind}^{3} C_p \quad (3)$$

Where, R = Radius of the blade (m).

B. BESS-STATCOM

The battery energy storage system (BESS) is used as an energy storage element for the purpose of voltage regulation [1]. The BESS will naturally maintain dc capacitor voltage constant and is best suited in STATCOM since it rapidly injects or absorbs reactive power to stabilize the grid system. When power fluctuation occurs in the system, the BESS is used to level the power fluctuation by charging and discharging operation. The battery is connected in parallel to the dc capacitor of STATCOM.

C. System Operation

The shunt connected STATCOM with battery energy storage is connected at the interface of the induction generator and non-linear load at the PCC [4]. The Fig.1 represents the system operational scheme in grid system. The STATCOM output is varied according to the control strategy, so as to maintain the power quality norms in the grid system. The current control strategies for STATCOM are the Bang-Bang controller and fuzzy logic controller. A single STATCOM using insulated gate bipolar transistors is proposed to have a reactive power support to the induction generator and to the nonlinear load in the grid system.

D. Control Scheme

The first control scheme approach is based on injecting the currents into the grid using "bang-bang controller" [1].The controller uses a hysteresis current controlled technique as shown in Fig 2. Using such a technique, the controller keeps the control system variable between the boundaries of hysteresis area and gives correct switching signals for STATCOM operation. The current controller block receives reference current and actual current as inputs and are subtracted so as to activate the operation of STATCOM in current control mode [5]. The second control scheme is fuzzy logic controller. The inputs to the controller 'change in grid voltage (ΔV)' and 'change in grid current (ΔI)' and is represented as membership functions of the controller .The output is correct switching signals for IGBTs of STATCOM (ΔU).

E Grid Synchronization

In the three-phase balance system, the RMS source voltage amplitude is calculated from the source phase voltages (V_{sa}, V_{sb}, V_{sc}) and is expressed as sample template (sampled peak voltage),V_{sm}:

$$V_{sm} = \sqrt{\{2/3(V_{sa}^2+V_{sb}^2+V_{sc}^2)\}} \quad (4)$$

The in-phase unit vectors are obtained from source voltage in each phases and the RMS value of unit vector is shown below

$$U_{sa} = V_{sa}/V_{sm}$$
$$U_{sb} = V_{sb}/V_{sm}$$
$$U_{sc} = V_{sc}/V_{sm} \quad (5)$$

Where 'I' is proportional to magnitude of filtered source voltage for respective phases. This ensures that the source current is controlled to be sinusoidal [6].

F. Bang-Bang Current Controller

It is implemented in the current control scheme. The reference current is generated as in equation (6) and actual current are detected by current sensors and are subtracted for obtaining a current error for a hysteresis based bang-bang controller. Thus the ON/OFF switching signals for IGBTs of STATCOM are derived from hysteresis controller [1] .The switching function S_A for phase 'a' is expressed as:

$$(i_{sa} - i_{sa}^*) < HB = S_A = 1$$
$$(i_{sa} - i_{sa}^*) > HB = S_A = 0 \quad (7)$$

This is same for phases 'b' and 'c'.

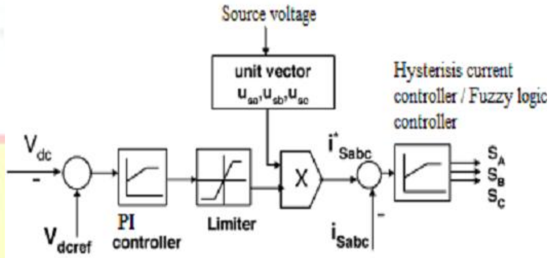

Fig.2.Control Scheme.

G. Fuzzy Logic Controller

In a fuzzy logic controller, the control action is determined from the evaluation of a set of simple linguistic rules. The development of the rules requires a thorough understanding of the process to be controlled, but it does not require a mathematical model of the system. The objectives include excellent rejection of input supply variations both in utility and in wind generating system and load transients. Expert knowledge can also be participated with ease that is significant when the rules developed are intuitively inappropriate [7]. The rule base developed is reliable since it is complete and generated sophistically without using extrapolation. In this project, fuzzy control is used to control the firing angle for the switches of the VSI of STATCOM. In this design, the fuzzy logic based STATCOM has two inputs 'change in voltage(ΔV)' and 'change in current(ΔI)' and one control output(ΔU). Firstly the input values will be converting to fuzzy variables. This is called fuzzification. After this, fuzzy inputs enter to rule base or interface engine and the outputs are sent to defuzzification to calculate the final outputs. These processes are demonstrated in Fig. 3. Here seven fuzzy subsets have been used for two inputs. These are: PB (positive big), PM (positive medium), PS (positive small), ZE (zero), NS (negative small), NM (negative medium) and NB (negative big). We use Gaussian membership functions [8] and 49 control rules are developed, which are shown in table 1. Fuzzification: It is the process of representing the inputs as suitable linguistic variables .It is first block of controller and it converts each piece of input data to a degree of membership function. It matches the input data with conditions of rules and determines how well the particular input matches the conditions of each rule.

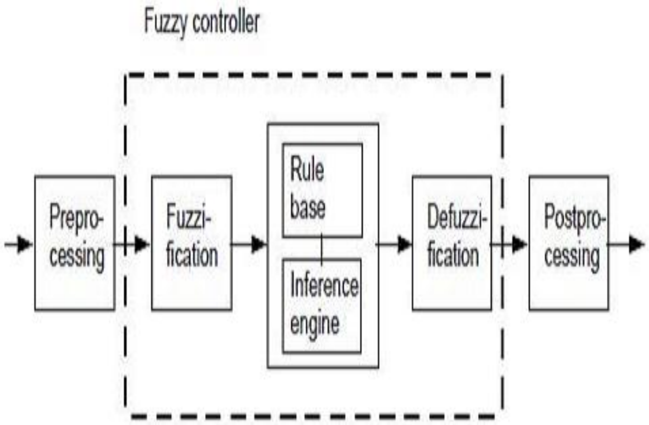

Fig.3. Fuzzy control block diagram.

Table I .Control Rules

ΔI / ΔV	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NM	NM	NS	ZE	PS
NS	NB	NM	NS	NS	ZE	PS	PM
ZE	NM	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PS	PM	PB
PM	NS	ZE	PS	PM	PM	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

The membership functions for the inputs (for ΔV and ΔI) are shown in Fig.4 and Fig.5. The number of fuzzy levels is not fixed and it depends on the input resolution needed in an application. The larger the number of fuzzy levels, the higher is the input resolution. The fuzzy control implemented here uses sinusoidal fuzzy-set values Decision making: The control rules that associate the fuzzy output to the fuzzy inputs are derived from general knowledge of the system behaviour. However, some of the control actions in the rule table are also developed using "trial and error" and from an "intuitive" feel of the process to be controlled. In this effort, the control rules for the STATCOM in Table 1 resulted from the understanding of STATCOM's behaviour and experimental tests of its VSI's performance.

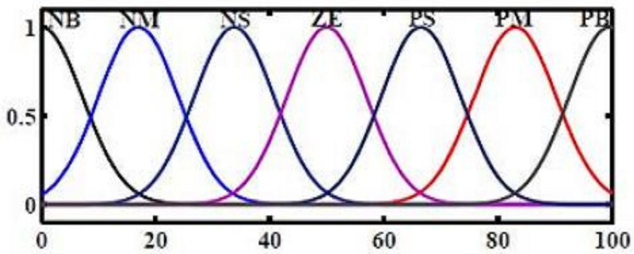

Fig.4. Membership function for ΔI

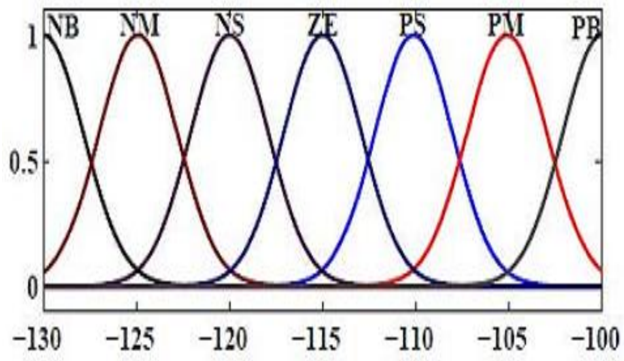

Fig.5. Membership function for ΔV.

Defuzzification: It is the Process of converting fuzzy flied output into a crisp value. In the defuzzification operation a logical sum of the results from each of the rules performed. This logical sum is the fuzzy representation of the change in firing angle (output). A crisp value for the change in firing angle is calculated. Correspondingly the grid current changes and improves the power quality.

III. MATLAB/SIMULINK RESULTS

case1: linear balanced load

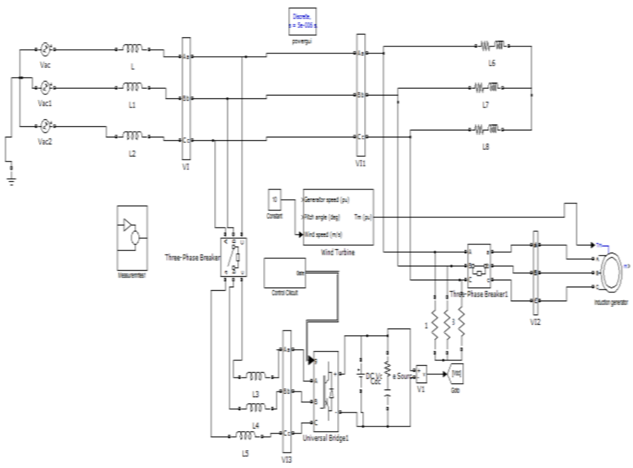

Fig.6.Matlab/Simulink Model of STATCOM with linear Balanced load.

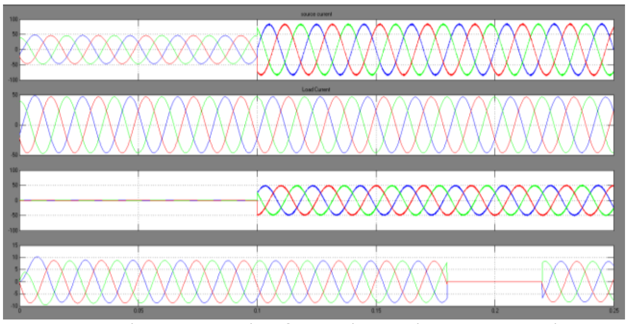

Fig.7. Simulation results for Balanced Linear Load using fuzzy logic control (a) Source current. (b) Load current. (c) Compensator Current. (d) Wind Generator (Induction Generator) Current.

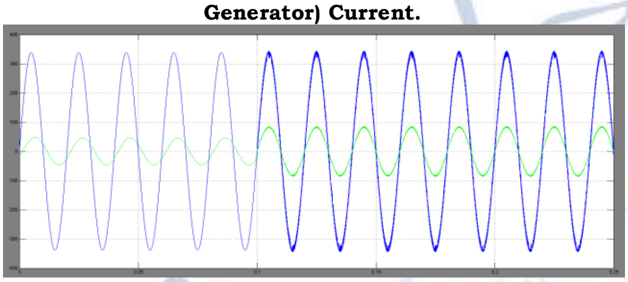

Fig.8 Power Factor for Balanced Linear Load with Conventional Fuzzy Controller.

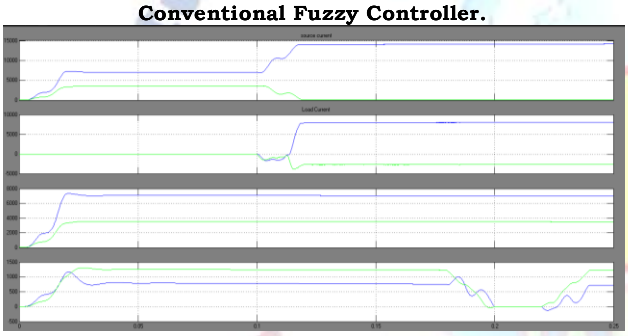

Fig.9. Real and reactive power for (a) load (b) source (c) STATCOM (d) wind energy generating system.

Case2: linear unbalanced load

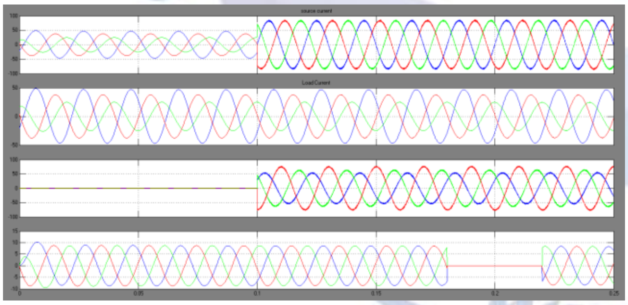

Fig.10. Simulation results for unbalanced Linear Load using fuzzy logic control (a) Source current. (b) Load current. (c) Compensator Current. (d) Wind Generator (Induction Generator) Current.

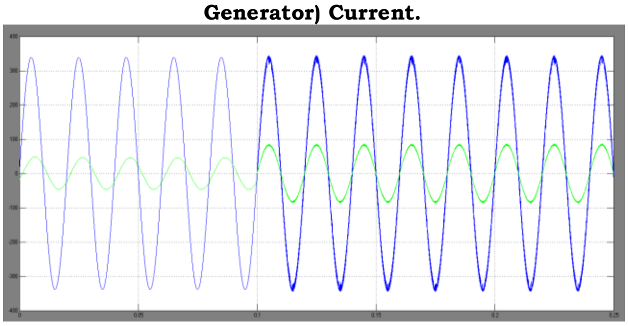

Fig.11. Power Factor for unbalanced Linear Load with Conventional Fuzzy Controller.

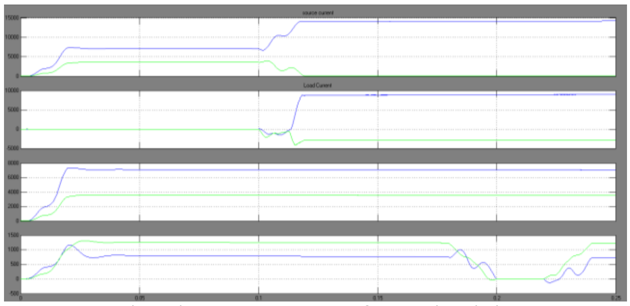

Fig.12. Real and reactive power for (a) load (b) source (c) STATCOM (d) wind energy generating system.

Case3: non-linear unbalanced load

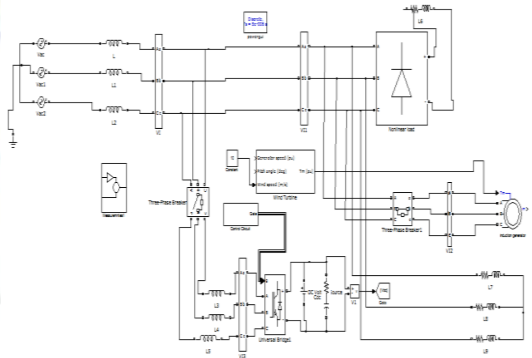

Fig.13. Matlab/Simulink of Proposed Statcom-Power Circuit.

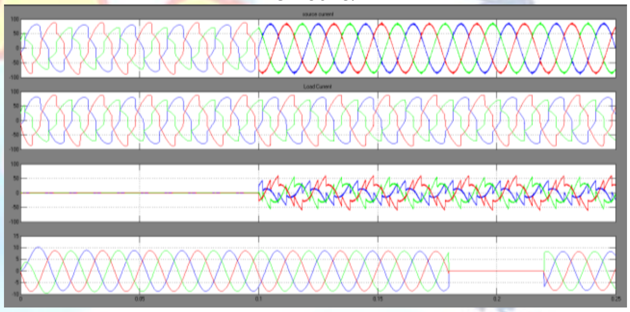

Fig.14. Simulation results for unbalanced non-Linear Load using fuzzy logic control (a) Source current. (b) Load current. (c) Compensator Current. (d) Wind Generator (Induction Generator) Current.

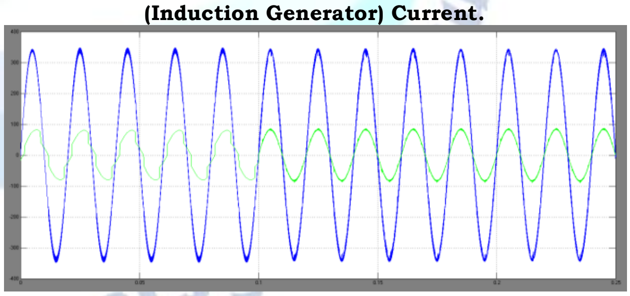

Fig.15. Power Factor for unbalanced non-Linear Load with Conventional Fuzzy Controller.

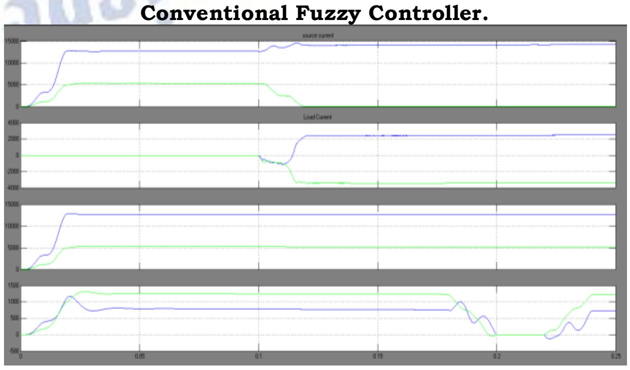

Fig.17. Real and reactive power for (a) load (b) source (c) STATCOM (d) wind energy generating system.

Here simulation is carried out in several cases and the complete model of STATCOM with several control strategies are designed by using Matlab/Simulink platform.

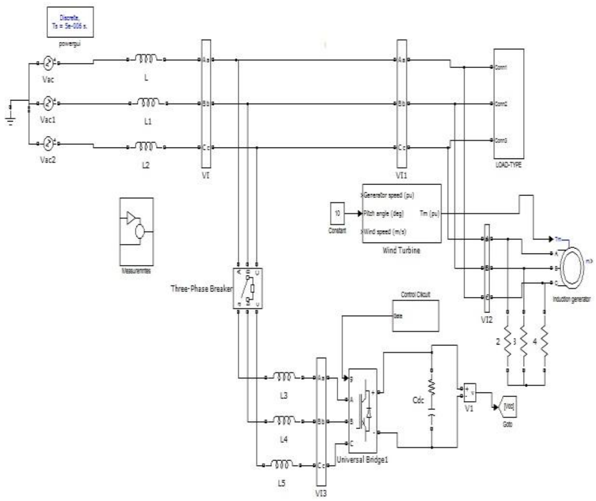

Fig.18. Matlab/Simulink of Proposed Statcom-Power Circuit.

Fig.18. Matlab/Simulink Model of proposed power circuit, along with control circuit. The power circuit as well as control system are modeled using Power System Block set and Simulink. Here simulation is carried out at different control strategies.

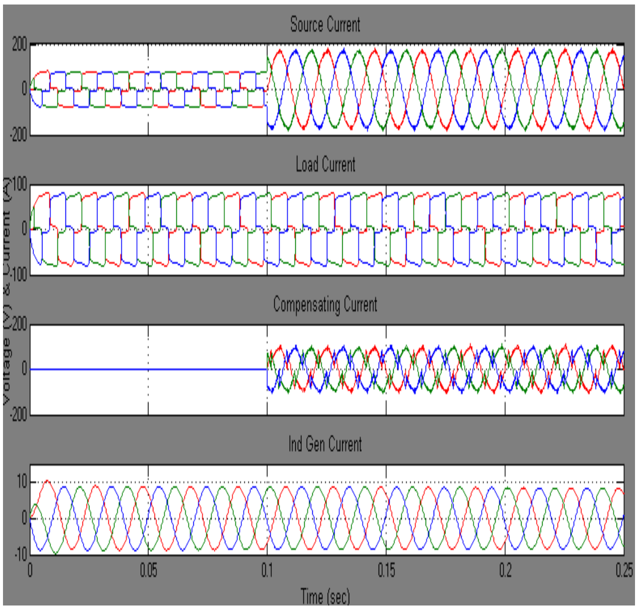

Fig.19. Simulation results for Balanced Non Linear Load using fuzzy logic control (a) Source current. (b) Load current. (c) Compensator Current. (d) Wind Generator (Induction Generator) Current.

Fig.19.shows the source current, load current and compensator current and induction generator currents plots respectively with conventional fuzzy controller. Here compensator is turned on at 0.1 seconds, before we get some harmonics coming from non-linear load, then distorts our parameters and get sinusoidal when compensator is in on.

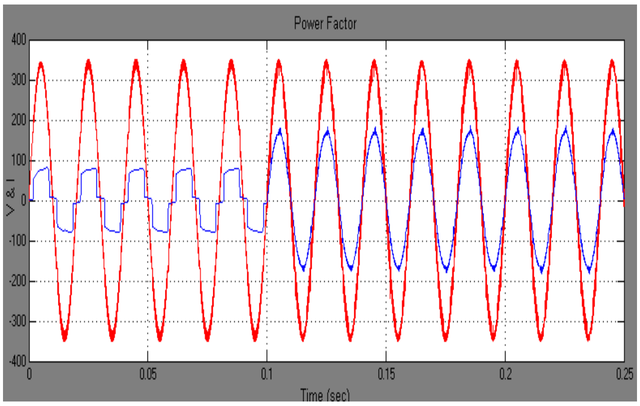

Fig.20. Power Factor for Balanced Non- Linear Load with Conventional Fuzzy Controller.

Fig.20. shows the power factor it is clear from the figure after compensation power factor is unity.

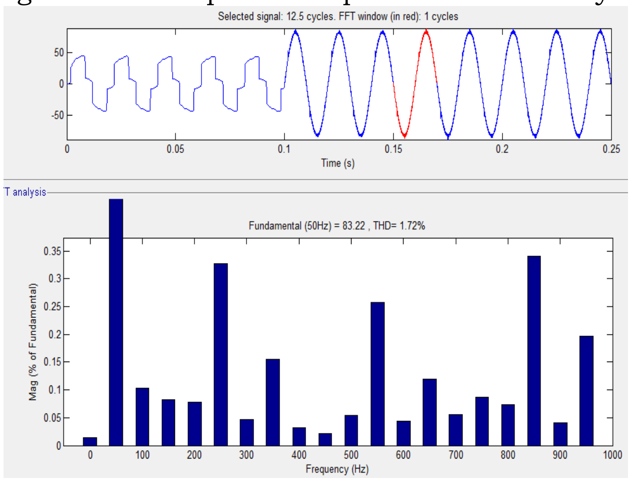

Fig.21.THD analysis of Source Current with Fuzzy Logic Control.

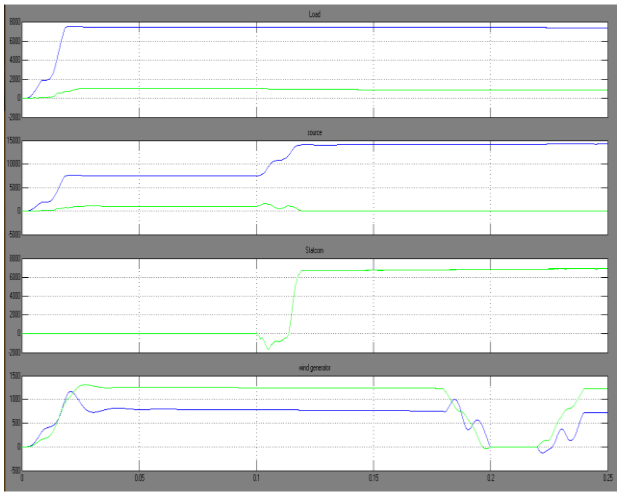

Fig.22. Real and reactive power for (a) load (b) source (c) STATCOM (d) wind energy generating system.

IV. Conclusion

STATCOM system is an efficient mean for mitigation of PQ disturbances introduced to the grid by DERs. STATCOM compensator is a flexible device which can operate in current control mode for compensating voltage variation, unbalance and reactive power and in voltage control mode as a voltage stabilizer. STATCOM injects current to the grid and it cancel out the reactive and harmonic parts of the induction generator current and load current .When we are reducing the wind generating system output ,it will not affect the source current magnitude. STATCOM control algorithm is flexible and it has been observed to be capable of correcting power factor to unity, eliminate harmonics in supply currents and provide load balancing. It is also able to regulate voltage at PCC. The control algorithm of STATCOM has an inherent property to provide a self-supporting DC bus of STATCOM. It has been found that the STATCOM system reduces THD in the supply currents for non-linear loads. Rectifier-based non-linear loads generated harmonics are eliminated by STATCOM. When single-phase rectifier loads are connected, STATCOM currents balance these unbalanced load currents.

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