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A novel Fuzzy Based STATCOM Control Scheme for the Grid Connected Wind Energy Generating System

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Abstract: Framework of a fuzzy logic controller utilizing the voltage as criticism for altogether enhancing the dynamic execution of compensator with great solidness component to be accomplished. The impacts of the power quality estimations are the dynamic power, responsive power, variety of voltage, gleam, sounds, and electrical conduct of exchanging operations. The establishments of wind turbine with the framework reasons power quality issues are resolved. A Novel Fuzzy based STATCOM (Static synchronous Compensator) is a shunt, flexible AC transmission system (FACTS) gadget with some canny information, used to remunerate the responsive power in a lattice, and by this balance out the network voltage. Static compensator (STATCOM) with a battery energy storage system (BESS) is joined at the purpose of basic coupling to moderate the power quality issues with great steadiness element, low mistake values. The matrix associated wind energy era frameworks for power quality change by utilizing STATCOM with a few controllers are proposed. Here two control plans for STATCOM are thought about: Bang-Bang current controller and Fuzzy rationale controller. Blast Bang controller is a hysteresis current controlled procedure. The STATCOM control plan for the lattice joined wind energy era framework for power quality change is reproduced utilizing MATLAB/SIMULINK.

Keywords: Wind Power, Distribution Network, Induction Generator, STATCOM, Reactive Power, Harmonics, and Power Quality**.**

I.INTRODUCTION

The renewable energy resources like wind, hydro, biomass etc are necessary to sustainable growth and social progress. So the integration of wind energy into power system is used to minimize the environmental impact on conventional plant. A continuous proliferation of non-linear loads is due to the intensive use of power electronics converter-based power processing units in industries and residential applications. The non-linear loads generate serious harmonic currents and reactive power to the distribution and transmission loads generate serious harmonic currents and reactive power to the distribution and transmission System, which results in a low power factor, leads to voltage notch and reduces the utilization of the distribution system. Traditionally, current harmonics caused by non-linear loads have been dealt

with using passive filters consisting of capacitors, inductors and damping resistors. They provide simple solution but have large size and weight they cannot provide flexible compensation and may cause resonance problems.

Nowadays, the development of power electronics and microcontrollers makes it possible to convert active power filters, which can provide flexible current harmonics compensation and contribute to reactive power control and load balancing. Hence Power electronic based FACTS devices like STATCOM can be effectively utilized to improve the quality of power supplied to the customers [5].

There has been an extensive growth and quick development in the exploitation of wind energy in recent years. The individual units can be of large capacity up to 2MW, feeding in to distribution network, practically which customers connected in close proximity [6]. Today, more than 28000 wind generating turbines is successfully operating all over the world. in fixed speed wind turbine operation, all the fluctuations in wind speed are transmitted as the fluctuations in the mechanical torque, electrical power on the grid leads to large voltage fluctuations. during the normal, wind turbine produces a continuous variable output power. These power variations are mainly caused by the effect of turbulence, wind shear, and tower shadow and of control system in the power system. The power quality issues can be viewed with respect to the wind generation, transmission and distribution network, such as voltage sag, swells, flickers, harmonics etc.

However the wind generator introduces disturbances in to the distribution network. One of the simple methods of running a wind generating system is to use the induction generator connected directly to the grid system. The induction generator has inherent advantages of cost effectiveness and robustness. However; induction generators required reactive power for magnetization.

When the generated active power of an induction generator is varied due to wind, absorbed reactive power and terminal voltage of an induction generator can be significantly effected. A proper control scheme in wind energy generation system is required under normal operating condition to allow the proper control over the active power production. In the event of increasing grid disturbance, a battery energy storage system for wind energy generating system is generally required to compensate the fluctuation generated by wind turbine. A STATCOM – based control technology has been proposed for improving the power quality which can technically manages the power level associates with the commercial wind turbines. The proposed STATCOM control scheme for grid connected wind energy generation for power quality improvement has following objectives.

i) Unity power factor at the source side.

ii) Reactive power support only from STATCOM to wind generator and load.

iii) Simple bang-bang controller for STATCOM to achieve fast dynamic response.

II. Power Quality Issues And Its Consequences

A.International Electro Technical Commission Guidelines

The guidelines are provided for measurement of power quality of wind turbine. The International standards are developed by the working group of Technical Committee-88 of the International Electro technical Commission (IEC), IEC standard 61400 - 21, describes the procedure for determining the power quality characteristics of the wind turbine [7].

B. Voltage Variation

The voltage variation issue results from the wind velocity and generator torque. The voltage variation is directly related to real and reactive power variations. The voltage variation is commonly classified as under:

- Voltage Sag/Voltage Dips.
- Voltage Swells.
- Short Interruptions.
- Long duration voltage variation.

The voltage flicker issues be describes dynamic variations in the network caused by wind turbine or by varying loads. Thus the power fluctuation from wind turbine occurs during continuous operation. The amplitude of voltage fluctuation depends on grid strength, network impedance, and phase-angle and power factor of the wind turbines. It is defined as a fluctuation of voltage in a frequency 10–35 Hz. The IEC 61400-4-15 specifies a flicker meter that can be used to measure flicker directly.

C. Harmonics

The harmonic results due to the operation of power electronic converters. The harmonic voltage and current should be limited to the acceptable level at the point of wind turbine connection to the network. To ensure the harmonic voltage within limit, each source of harmonic current can allow only a limited contribution, as per the IEC-61400-36 guideline. The rapid switching gives a large reduction in lower order harmonic current compared to the line commutated converter, but the output current will have high frequency current and can be easily filter-out.

D. Wind Turbine Location in Power System

The way of connecting the wind generating system into the power system highly influences the power quality. Thus the operation and its influence on power system depend on the structure of the adjoining power network.

E. Self Excitation of Wind Turbine Generating System

The self excitation of wind turbine generating system (WTGS) with an asynchronous generator takes place after disconnection of wind turbine generating system (WTGS) with local load. The risk of self excitation arises especially when WTGS is equipped with compensating capacitor. The capacitor connected to induction generator provides reactive power compensation. However the voltage and frequency are determined by the balancing of the system. The disadvantages of self excitation are the safety aspect and balance between real and reactive power [5].

F. Consequences of the Issues

The voltage variation, flicker, harmonics causes the malfunction of equipments namely microprocessor based control system, programmable logic controller, adjustable speed drives flickering of lights and screen. it may leads to tripping of contractors tripping of protection devices, stoppage of sensitive equipments like personal computer, programmable logic control system and may stop the process and even can damage of sensitive equipments. thus it degrade the power quality in the grid.

III. Grid Coordination Rule

The American Wind Energy Association (AWEA) led the effort in the united state for adoption of the grid code for the inter-connection of the wind plants to the utility system. The first grid code was focused on the distribution level, after the blackout in the United State in August 2003. The United State wind energy industry took a stand in developing its own grid code for contributing to a stable grid operation. The rules for realization of grid operation of wind generating system at the distribution network are defined as-per IEC-61400-21. The grid quality characteristics and limits are given for references that the customer and the utility grid may expect. According to Energy-Economic Law, the operator of

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transmission grid is responsible for the organization and operation of interconnected system [6].

1) Voltage Rise (u): The voltage rise at the point of common coupling can be approximated as a function of maximum apparent power S_{max} of the turbine, the grid impedances R and X at the point of common coupling and the phase angle ϕ , given as

$$\Delta u = \frac{S_{max}(R_{cos\Phi} - X_{sin\Phi})}{U^2} -$$

Where Δu is voltage rise, S_{max} is Max apparent power, ϕ is phase difference, U is the nominal voltage of grid. The Limiting voltage rise value is $<2\%$.

2) Voltage Dips (d): The voltage dips is due to start up of wind turbine and it causes a sudden reduction of voltage. It is the relative % voltage change due to switching operation of wind turbine. The decrease of nominal voltage change is given in bellow.

$$d = K_u \frac{S_n}{S_K}$$

where d is relative voltage change, S_n rated apparent power, S_K short circuit apparent power, and K_u sudden voltage reduction factor. The acceptable voltage dips limiting value is $\leq 3\%$.

3) Flicker: The measurements are made for maximum number of specified switching operation of wind turbine with 10-min period and 2-h period are specified, as

$$P_{1t} = C(\Psi_K) \frac{S_n}{S_k}$$

Where P_{1t}— Long term flicker. $C(\Psi_K)$ Flicker coefficient calculated from Rayleigh distribution of the wind speed. The Limiting Value for flicker coefficient is about ≤ 0.4, for average time of 2 h.

4) Grid Frequency: The grid frequency in India is specified in the range of 47.5–51.5 Hz, for wind farm connection. The wind farm shall able to withstand change in frequency up to 0.5 Hz/s.

IV. Topology For Power Quality Improvement

The STATCOM based current control voltage source inverter injects the current into the grid in such a way that the source current are harmonic free and their phase-angle with respect to source voltage has a desired value. The injected current will cancel out the reactive part and harmonic part of the load and induction generator current, thus it improves the power factor and the power quality. To accomplish these goals, the grid volt-ages are sensed and are synchronized in generating the current command for the inverter. The proposed grid connected system is implemented for power quality improvement at point of common coupling (PCC), as shown in Fig.1 The grid connected system in Fig. 1, consists of wind energy generation system and battery energy storage system with STATCOM.

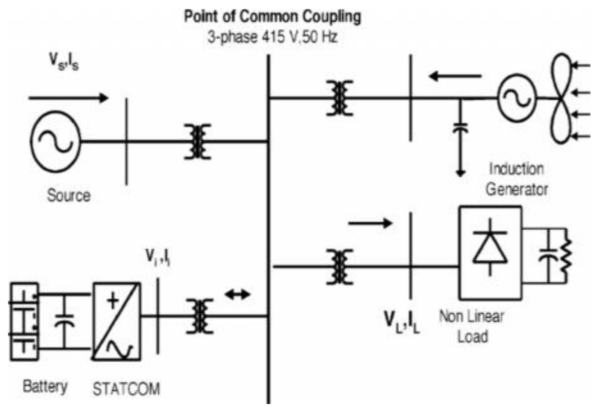

Fig: 1 Grid connected system for power quality Improvement.

A. Wind Energy Generating System

In this configuration, wind generations are based on constant speed topologies with pitch control turbine. 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 bellow.

$\boldsymbol{P_{wind}} = \frac{1}{2} \rho A V_{wind}^3$ Where ρ= air density (kg/m^3), A = area swept out by turbine blade (m^2), V_{wind}= wind speed (m/s). It is not possible to extract all kinetic energy of wind. Thus extracts a fraction of the power in wind called coefficient 'Cp' of the wind turbine, and is given by

$\boldsymbol{P_{mech}} = C_p P_{wind}$; where Cp is the power coefficient, depends on type and operating condition of wind turbine. This coefficient can be express as a function of tip speed ratio λ and pitch angle θ.The mechanical power produce by wind turbine is given as $P_{mech} = \frac{1}{2} \rho \pi R^2 V_{wind}^3 C_p$;where R is the radius of the baled(m).

B. Bess-Satcom

The battery energy storage system (BESS) is used as an energy storage element for the purpose of voltage regulation. The BESS will naturally maintain dc capacitor voltage constant and is best suited in STATCOM since it rapidly injects or absorbed reactive power to stabilize the grid system. It also controls the distribution and transmission system in a very fast rate. When power fluctuation occurs in the system, the BESS can be used to level the power fluctuation by charging and discharging operation. The battery is connected in parallel to the dc capacitor of STATCOM [10]. 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.

E. System Operation

The shunt connected STATCOM with battery energy storage is connected with the interface of the induction generator and non-linear load at the PCC in the grid system. The STATCOM compensator output is varied according to the controlled strategy, so as to maintain the power quality norms in the grid system. The current control strategy is included in the control scheme that defines the functional operation of the STATCOM compensator in the power system.

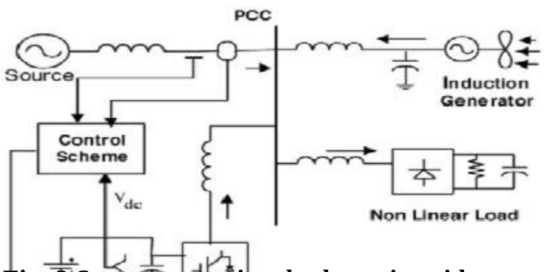

Fig: 2 System operational scheme in grid system.

A single STATCOM using insulated gate bipolar transistor is proposed to have a reactive power support, to the induction generator and to the nonlinear load in the grid system. The main block diagram of the system operation scheme is shown in fig.2.

F. Control Scheme

The control scheme approach is based on injecting the currents into the grid using "bang-bang controller." The controller uses a hysteresis current controlled technique. Using such technique, the controller keeps the control system variable between boundaries of hysteresis area and gives correct switching signals for STATCOM operation. The control system scheme for generating the switching signals to the STATCOM is shown in Fig. 3.

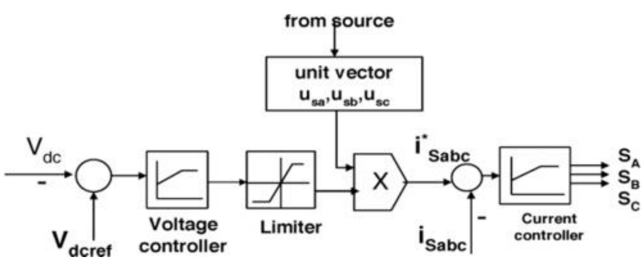

Fig: 3 Control system scheme

The control algorithm needs the measurements of several variables such as three phase source current, DC voltage, inverter current with the help of sensor. The current control block, receives an input of reference current and actual current are subtracted so as to activate the operation of STATCOM in current control mode.

F. Grid Synchronization

In three-phase balance system, the RMS voltage source amplitude is calculated at the sampling frequency from the source phase voltage (V_{sa}, V_{sb}, V_{sc}) and is expressed, as sample tem-plate V_{sm}, sampled peak voltage, as bellow,

$$V_{sm} = \left\{ \frac{2}{3} \left(V_{sa}^2 + V_{sb}^2 + V_{sc}^2 \right) \right\}^{1/2}.$$

The in-phase unit vectors are obtained from AC source phase voltage and the RMS value Of unit vector (u_{sa}, u_{sb}, u_{sc}) as shown in bellow,

$U_{sa} = V_{sa}/V_{sm}, U_{sb} = V_{sb}/V_{sm}, U_{sc} = V_{sc}/V_{sm}$.

The in-phase generated reference currents are derived using in-phase unit voltage template as in bellow,

$i^{*}_{sa} = \text{I}.\, u_{sa}$, $i^{*}_{sb} = \text{I}.u_{sb}$, $i^{*}_{sc} = \text{I}.\, u_{sc}$.

Where I is proportional to magnitude of filtered source voltage for respective phases. This ensures that the source current is controlled to be sinusoidal. The unit vectors implement the important function in the grid connection for the synchronization for STATCOM. This method is simple, robust and favorable as compared with other methods.

E. Bang-Bang Current Controller

Bang-Bang current controller is implemented in the current control scheme. The reference current is generated 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 IGBT of STATCOM are derived from hysteresis controller the switching function

S_A for phase 'a' is expressed as bellow, $i_{sa} < (i^{*}_{sa}$ - HB) $\rightarrow S_A = 0$.

$i_{sa} > (i^{*}_{sa}$ - HB) $\rightarrow S_A = 1$.

where HB is a hysteresis current-band, similarly the switching function S_B, S_C can be derived for phases "b" and "c".

V. About Fuzzy Logic Controller

L. A. Zadeh presented the first paper on fuzzy set theory in 1965. Since then, a new language was developed to describe the fuzzy properties of reality, which are very difficult and sometime even impossible to be described using conventional methods. Fuzzy set theory has been widely used in the control area with some application to power system [5]. A simple fuzzy logic control is built up by a group of rules based on the human knowledge of system behavior. Matlab/Simulink simulation model is built to study the dynamic behavior of converter. Furthermore, design of fuzzy logic controller can provide desirable both small signal and large signal dynamic performance at same time, which is not possible with linear control technique. Thus, fuzzy logic controller has been potential ability to improve the robustness of converters. The basic scheme of a fuzzy logic controller is shown in Fig 6 and consists of four principal components such as: a fuzzy-fication interface, which converts input data into suitable linguistic values; a knowledge base, which consists of a data base with the necessary linguistic definitions and the control rule set; a decision-making logic which, simulating a human decision process, infer the fuzzy control action from the knowledge of the control rules and linguistic variable definitions; a de-fuzzification interface which yields non fuzzy control action from an inferred fuzzy control action [10].

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

Fuzzyfication: 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

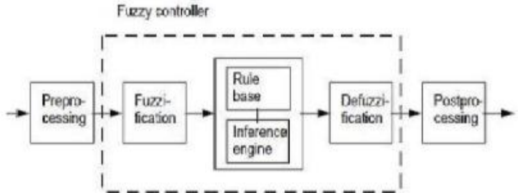

Fig:4 fuzzy control block diagram

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.5 and Fig.6. 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.

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 paper, 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. 4.
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 and are shown in the tabular form.1.

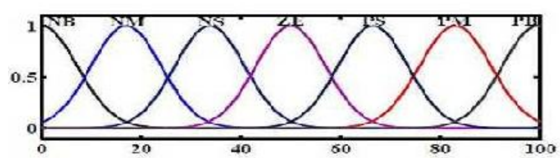

Fig: 5 Membership function for ΔI

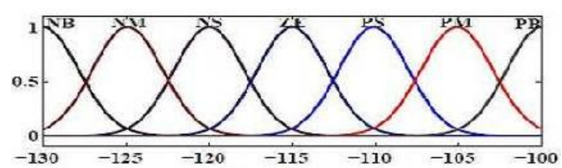

Fig: 6 Membership function for ΔV

Defuzzification: It is the Process of converting fuzzified 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.

VI. Matlab/Simulink Modeling & Results

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.

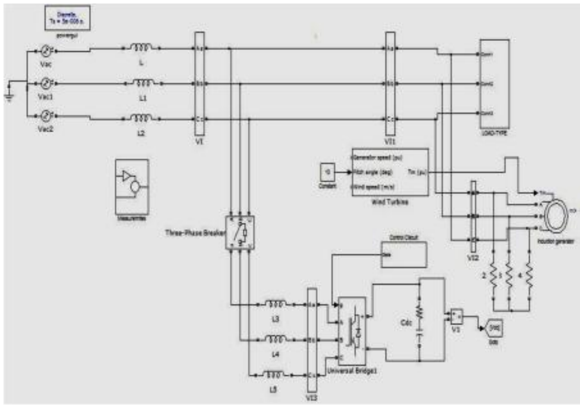

Fig.7 Matlab/Simulink of Proposed Statcom-Power Circuit

S.N.	Parameters	Ratings
1	Grid Voltage	3-phase ,415V,50 Hz
2	Induction Motor/Generator	3.35 kVA,415V, 50 Hz, P = 4, Speed = 1440 rpm, Rs = 0.01Ω, Rr=0.015Ω,Ls =0.06H,Lr=0.06H
3	Line Series Inductance	0.05mH
4	Inverter Parameters	DC Link Voltage = 800V, DC link Capacitance = 100 μF. Switching frequency = 2 kHz,
5	IGBT Rating	Collector Voltage =1200V, Forward Current =50A,Gate voltage =20V, Power dissipation = 310W
6	Load Parameter	Non-linear Load 25kW.

Table-2 system parameters

Fig.7 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,

1). Proposed BESS-STATCOM with Conventional PI Controller.

2). Proposed BESS-STATCOM with Intelligence based Fuzzy Controller,

3). Proposed BESS STATCOM with Intelligence based Novel Fuzzy Controller.

Case1: Proposed BESS-STATCOM with Conventional PI Controller.

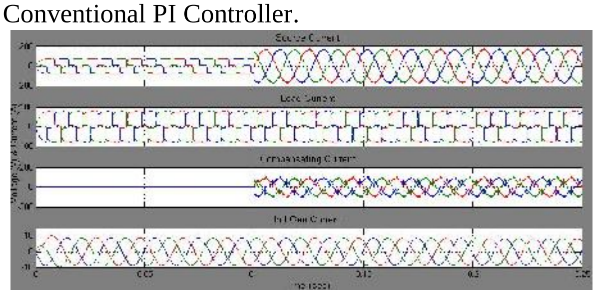

Fig.8. shows Simulation results for Balanced Non Linear Load (a)Source current. (b)Load current. (c) Compensator Current. (d)Wind Generator (Induction Generator) Current.

Fig. 8 shows the source current, load current
And compensator current and induction generator currents plot respectively with conventional PI 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.

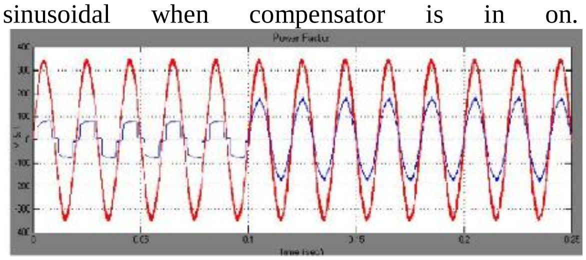

Fig.9 Power Factor for Balanced Non- Linear Load with Conventional PI Controller.

Fig. 9 shows the power factor it is clear from the figure after compensation power factor isUnity.

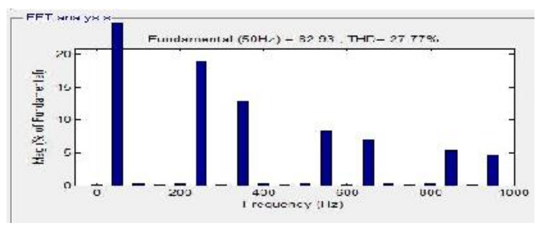

Fig. 10 FFT Analysis of Phase-A Source Current for Balanced Non-Linear Load without compensation scheme.

Fig.10 shows the FFT Analysis of Phase-A Source Current for Balanced Non-Linear Load without any compensation, here we get total THD is 27.77%.

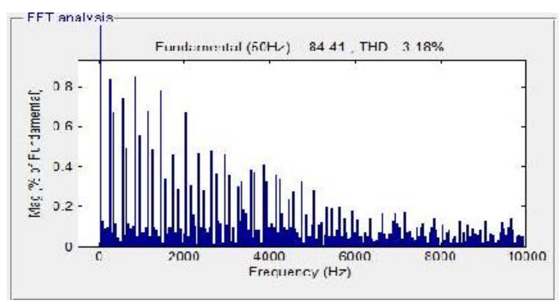

Fig. 11 FFT Analysis of Phase-A Source Current for Balanced Non Linear Load.

Fig.11 shows the FFT Analysis of Phase-A Source Current for Balanced Non-Linear Load, here we get total THD is 3.18%.

Case 2: Proposed BESS-STATCOM with Intelligence based Fuzzy Controller.

Fig.12 Simulation results for Balanced Non Linear Load (a) Source current. (b) Load current. (c) Compensator Current. (d)Wind Generator (Induction Generator) Current.

Fig.12 shows the source current, load current and compensator current and induction generator currents plots respectively with Fuzzy controller.

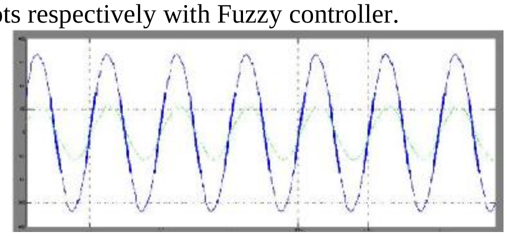

Fig.13 power factor for balanced non linear load with intelligence base fuzzy controller

Fig.13 shows the power factor it is clear from the figure after compensation power factor is unity.

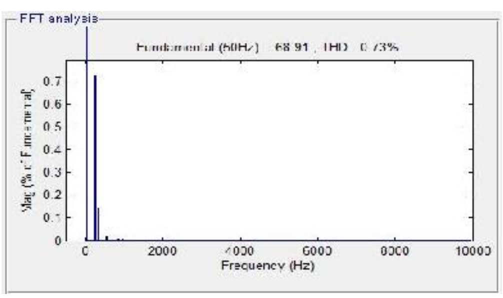

Fig. 14 FFT Analysis of Phase-A Source Current for Balanced Non-Linear Load with Intelligence based Fuzzy Controller

Fig.14 shows the FFT Analysis of Phase-A Source Current for Balanced Non-Linear Load, here we get 0.73%.

Case 3: Proposed BESS-STATCOM with Intelligence based Novel Fuzzy Controller

Fig.15 Simulation results for Balanced Non Linear Load(a)Source current. (b) Load current. (c) Compensator Current. (d)Wind Generator (Induction Generator) Current.

Fig. 15 shows the source current, load current and compensator current and induction generator currents plots respectively with Intelligence based Novel-Fuzzy controller.

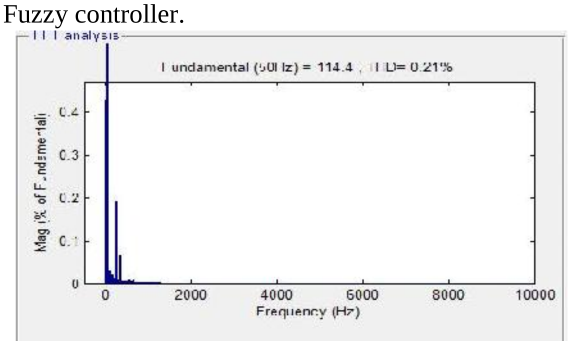

Fig. 16 FFT Analysis of Phase-A Source Current for Balanced Non-Linear Load with Intelligence based Novel Fuzzy Controller.

Fig.16 shows the FFT Analysis of Phase-A Source Current for Balanced Non-Linear Load, here we get 0.21%.

VII. Conclusion

The developments in power electronics and semiconductor technology have lead improvements in power electronic systems. A Novel Fuzzy based STATCOM control scheme for reactive power compensation and harmonic reduction in grid connected wind generating system feeding different load conditions such as balanced, load conditions with different controllers. The Simulation results shows the grid voltage and current are in-phase, making the power factor unity, which implies that the reactive power demand of Induction generator and load is no longer, fed by the grid rather it is supplied by the STATCOM. This paper has presented a novel fuzzy based STATCOM control of an existing grid interfacing inverter using conventional PI controller & fuzzy logic controller to improve the quality of power at PCC for a 3-phase 3-wire system. It has been shown that the grid-interfacing inverter can be effectively utilized for power conditioning without affecting its normal operation of real power transfer. By using conventional controller we get THD value is 3.18%, but using the fuzzy logic controller THD value is 0.73% and with novel fuzzy controller value attain 0.21%, to eliminate the error and achieve good stability factor and error free response.

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