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A Novel Improved Performance of Intelligence Based BESS-STATCOM for Power Quality Improving Features

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Abstract: ***The design of a fuzzy logic controller using the voltage as feedback for significantly improving the dynamic performance of converter. 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 equipments. 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. While connecting wind turbine to grid it is important to understand source of disturbance that affect the power quality. In this paper Intelligence controlled Static Compensator (STATCOM) is connected at a point of common coupling with a battery energy storage system (BESS) to rectify the power quality problems. The battery energy storage used to maintain constant real power from varying wind power. The amount of energy consumed or given to the grid can be view through an online smart meter connected in the circuit. Using the online smart meter the utility can view the energy consumption of each system simultaneously. So the utility can coordinate all the system effectively.The FACTS Device (STATCOM) control scheme for the grid connected wind energy generation system to improve the power quality is simulated using MATLAB/SIMULINK.***

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

I INTRODUCTION

To have sustainable growth and social progress, it is necessary to meet the energy need by utilizing the renewable energy resources like wind, biomass, hydro, co-generation, etc. In sustainable energy system, energy conservation and the use of renewable source are the key paradigm. The need to integrate the renewable energy like wind energy into power system is to make it possible to minimize the environmental impact on conventional plant [1]. The integration of wind energy into existing power system presents technical challenges and that requires consideration of voltage regulation, stability, power quality problems. The power quality is an essential customer-focused measure and is greatly affected by the operation of a distribution and transmission network. The issue of power quality is of great importance to the wind turbine [2]. 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 2 MW, feeding into distribution network, particularly with customers connected in close proximity [3]. Today, more than 28 000 wind generating turbines are successfully operating all over the world. In the fixed-speed wind turbine operation, all the fluctuation in the wind speed are transmitted as fluctuations in the mechanical torque, electrical power on the grid and leads to large voltage fluctuations. 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 into 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 require 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 affected. A proper control scheme in wind energy generation system is

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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.

In recent years power electronic converters are widely used in industrial as well as domestic applications for the control of power flow for automation and energy efficiency. Most of the time these converters draw harmonic current and reactive power from AC source and causes the power quality problems [19]. STATCOM is most effective for harmonic compensation. Different types, such as shunt and series active power filters are used effectively [2].

Recently Active Conditioners such as STATCOM is used to overcome these problems and also compensating the harmo nics and suppressing the reactive power simultaneously due to fluctuating loads. To overcomes the above disadvantages; STATCOM is best suited for reactive power compensation and harmonic reduction. It is based on a controllable voltage source converter (VSC). In normal operating system we need a control circuit for the active power production. For reducing the disturbance we use a battery storage system. The voltage source inverter is controlled by using the current control mode.

The proposed system with battery storage has the following objectives:

• Unity power factor and power quality at point of common coupling bus.

• Real and reactive power support only from wind generator and batteries to load.

• Self operation in case of grid failure. The utility companies can view the current, voltage and power of each system simultaneously by using the online smart metes. The utility can measure power generation of each system simultaneously.

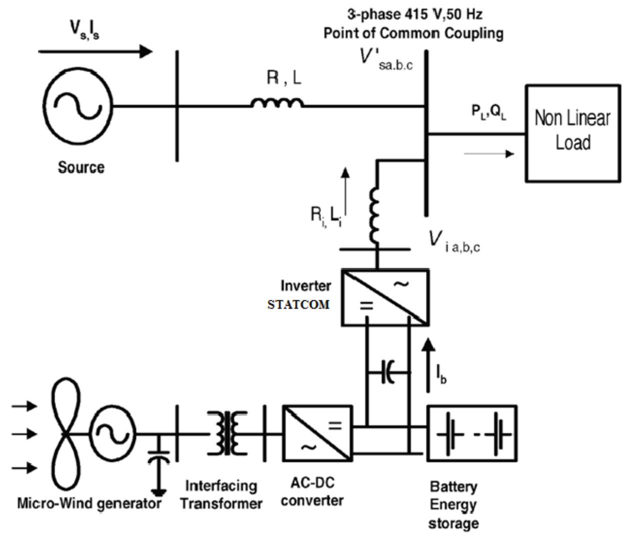

Fig.1 Scheme of wind generator with battery storage [6].

Conventionally, PI, PD and PID controller are most popular controllers and widely used in most power electronic appliances however recently there are many researchers reported successfully adopted Fuzzy Logic Controller (FLC) to become one of intelligent controllers to their appliances [3]. With respect to their successful methodology implementation, this kind of methodology implemented in this paper is using fuzzy logic controller with feed back by introduction of voltage respectively. The introduction of change in voltage in the circuit will be fed to fuzzy controller to give appropriate measure on steady state signal. The fuzzy logic controller serves as intelligent controller for this propose. This paper study demonstrates the power quality problem due to installation of wind turbine with the grid. In this proposed scheme 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. The STATCOM intelligence based control scheme for the grid connected wind energy generation system for power quality improvement is simulated using MATLAB/SIMULINK.

II. STATIC SYNCHRONOUS COMPENSATOR (STATCOM)

The STATCOM is a shunt-connected reactive-power compensation device that is capable of generating and/ or

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absorbing reactive power and in which the output can be varied to control the specific parameters of an electric power system. It is in general a solid-state switching converter capable of generating or absorbing independently controllable real and reactive power at its output terminals when it is fed from an energy source or energy-storage device at its input terminals. Specifically, the STATCOM, which is a voltage-source converter which when fed from a given input of dc voltage, produces a set of 3-phase ac-output voltages, each in phase with and coupled to the corresponding ac system voltage through a relatively small reactance (which is provided by either an interface reactor or the leakage inductance of a coupling transformer). The dc voltage is provided by an energy-storage capacitor.

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.

A STATCOM can improve power-system Performance like:

1. The dynamic voltage control in transmission and distribution systems,

2. The power-oscillation damping in power- transmission systems,

3. The transient stability,

4. The voltage flicker control, and

5. The control of not only reactive power but also (if needed) active power in the connected line, requiring a dc energy source.

A STATCOM is analogous to an ideal synchronous machine, which generates a balanced set of three sinusoidal voltages at the fundamental frequency with controllable amplitude and phase angle. This ideal machine has no inertia, is practically instantaneous, does not significantly alter the existing system impedance, and can internally generate reactive (both Capacitive and inductive) power.

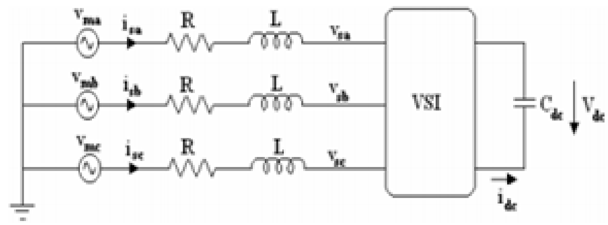

Fig. 2. Equivalent circuit of STATCOM

Fig.2. shows the equivalent circuit of the STATCOM connected to the power system. The reactive power supplied by the STATCOM is either inductive or capacitive depending upon the relative magnitude of fundamental component of vs with respect to vm. If |v
m| > |vs|, the VSI draws reactive power from the ac bus whereas if |v m| < |vs|, it supplies reactive power to the ac system

III POWER QUALITY ISSUES

A. 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 issue 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.

B. 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. The rapid switching gives a large reduction in lower order harmonic current com- pared to the

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line commutated converter, but the output current will have high frequency current and can be easily filter out. The harmonic distortion is assessed for variable speed turbine with a electronic power converter at the point of common connection [9]. The total harmonic voltage distortion of voltage is given as in (1)

$$V_{\mathrm{THD}} = \sqrt{\sum_{h=2}^{40} \frac{V_n^2}{V_1} 100} \quad (1)$$

Where Vn is the nth harmonic voltage and V1 is the fundamental frequency (50) Hz. The THD limit for 132 KV is <3 %.THD of current ITHD is given as in (2)

$$I_{\mathrm{THD}} = \sqrt{\sum \frac{I_n}{I_1} 100} \quad (2)$$

Where In is the nth harmonic current and I1 is the fundamental frequency (50) Hz. The THD of current and limit for 132 KV is <2.5%.

C. Reactive Power:

Traditional wind turbine is equipped with induction generator. Induction Generator is preferred because they are inexpensive, rugged and requires little maintenance. Unfortunately induction generators require reactive power from the grid to operate. The interactions between wind turbine and power system network are important aspect of wind generation system. When wind turbine is equipped with an induction generator and fixed capacitor are used for reactive compensation then the risk of self excitation may occur during off grid operation. Thus the sensitive equipments may be subjected to over/under voltage, over/under frequency operation and other disadvantage of safety aspect. The effective control of reactive power can improve the power quality and stabilize the grid. The suggested control technique is capable of controlling reactive power to zero value at point of common connection (PCC).

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. The induction generators are widely used, due to theadvantage of cost effectiveness, robustness, ruggedness, simplicity and requirement of no brush and commutators.However; induction generators require 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 affected.

During the operation induction generator draws reactive power from the grid for its magnetization. Non linear load distorts the grid current waveform and also increase the harmonic component. Due to this, grid current is not in phase with the grid voltage and its wave shape is also different from sine wave which is shown in fig 4. Hence the power factor is not unity. Reactive power requirement of induction generatorand load is supplied by the grid.

IV. REFERENCE CURRENT GENERATION FOR STATCOM

Reference current for the STATCOM is generated based on instantaneous reactive power theory [7][10]. A STATCOM injects the compensation current which is a sum of reactive component current of IG, non-linear load and harmonic component current of non-linear load. P-Q theory gives a generalized definition of instantaneous reactive power, which is valid for sinusoidal or non sinusoidal, balanced or unbalanced, three-phase power systems with or without zero sequence currents and/or voltages.

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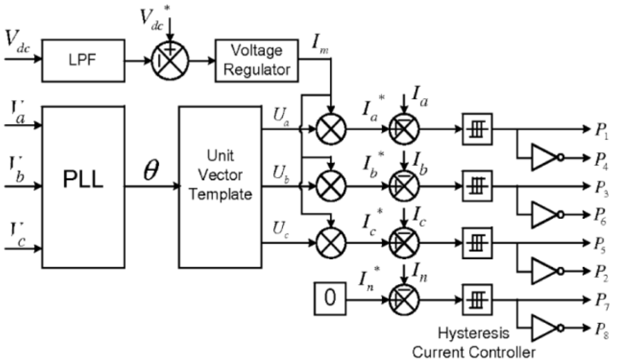

Fig. 3. Block diagram representation of grid-interfacing inverter control.

The control diagram of grid- interfacing inverter for a 3-phase 3-wire system is shown in Fig. 3. While performing the power management operation, the inverter is actively controlled in such a way that it always draws/ supplies fundamental active power from/ to the grid. If the load connected to the PCC is non-linear or unbalanced or the combination of both, the given control approach also compensates the harmonics, unbalance, and neutral current. The duty ratio of inverter switches are varied in a power cycle such that the combination of load and inverter injected power appears as balanced resistive load to the grid. The regulation of dc-link voltage carries the information regarding the exchange of active power in between renewable source and grid. Thus the output of dc-link voltage regulator results in an active current (Im). The multiplication of active current component (Im). With unity grid voltage vector templates (U_a,U_b, and U_c) generates the reference grid currents (I_a^*, I_b^*, and I_c^*). The grid synchronizing angle (θ) obtained from phase locked loop (PLL) is used to generate unity vector template as [9]–[11]

$$U_a = \mathrm{Sin}(\theta) \tag{3}$$

$$U_b = \mathrm{Sin}(\theta - \frac{2\pi}{3}) \tag{4}$$

$$U_c = \mathrm{Sin}(\theta + \frac{2\pi}{3}) \tag{5}$$

The actual dc-link voltage (V_{dc}) is sensed and passed through a first-order *low pass filter* (LPF) to eliminate the presence of switching ripples on the dc-link voltage and in the generated reference current signals. The difference of this filtered dc-link voltage and reference dc-link voltage (V^*_{dc}) is given to a discrete- PI regulator to maintain a constant dc-link voltage under varying generation and load conditions. The dc-link voltage error V_{dcerr} (n) at nth sampling instant is given as:

$$V_{\mathrm{dcerr}(n)} = V^*_{\mathrm{dc}(n)} - V_{\mathrm{dc}(n)}. \tag{6}$$

The output of discrete-PI regulator at th sampling instant is expressed as

$$I_{m(n)} = I_{m(n-1)} + K_{PV_{dc}}(V_{dcerr(n)} - V_{dcerr(n-1)}) + K_{IV_{dc}} V_{dcerr(n)} \tag{7}$$

Where K_{PVdc} = 10 and K_{IVdc} = 0.05 are proportional and integral gains of dc-voltage regulator. The instantaneous values of reference three phase grid currents are computed as

$$I_a^* = I_m \cdot U_a \tag{8}$$

$$I_b^* = I_m \cdot U_b \tag{9}$$

$$I_c^* = I_m \cdot U_c. \tag{10}$$

The neutral current, present if any, due to the loads connected to the neutral conductor should be compensated by forth leg of grid-interfacing inverter and thus should not be drawn from the grid. In other words, the reference current for the grid neutral current is considered as zero and can be expressed as

$$I_n^* = 0. \tag{11}$$

The reference grid currents (I^*a, I^*b,I^*c and I^*n) are compared with actual grid currents (Ia, Ib,Ic and In) to compute the current errors as

$$I_{\mathrm{aerr}} = I_a^* - I_a \tag{12}$$

$$I_{\mathrm{berr}} = I_b^* - I_b \tag{13}$$

$$I_{\mathrm{cerr}} = I_c^* - I_c \tag{14}$$

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$$I_{\mathrm{nerr}} = I_n^* - I_n. \tag{15}$$

These current errors are given to hysteresis current controller. The hysteresis controller then generates the switching pulses (P_1 *to* P_8) for the gate drives of grid-interfacing inverter. The average model of 4-leg inverter can be obtained by the following state space equations

$$\frac{dI_{\mathrm{Inva}}}{dt} = \frac{(V_{\mathrm{Inva}} - V_a)}{L_{\mathrm{sh}}} \tag{16}$$

$$\frac{dI_{\mathrm{Invb}}}{dt} = \frac{(V_{\mathrm{Invb}} - V_b)}{L_{\mathrm{sh}}} \tag{17}$$

$$\frac{dI_{\mathrm{Invc}}}{dt} = \frac{(V_{\mathrm{Invc}} - V_c)}{L_{\mathrm{sh}}} \tag{18}$$

$$\frac{dI_{\mathrm{Invn}}}{dt} = \frac{(V_{\mathrm{Invn}} - V_n)}{L_{\mathrm{sh}}} \tag{19}$$

$$\frac{dV_{\mathrm{dc}}}{dt} = \frac{(I_{\mathrm{Invad}} + I_{\mathrm{Invbd}} + I_{\mathrm{Invcd}} + I_{\mathrm{Invnd}})}{C_{\mathrm{dc}}} \tag{20}$$

Where V_{Inva}, V_{Invb}, V_{Invc} and V_{Invn} are the three-phase ac switching voltages generated on the output terminal of inverter. These inverter output voltages can be modeled in terms of instantaneous dc bus voltage and switching pulses of the inverter as

$$V_{\mathrm{Inva}} = \frac{(P_1 - P_4)}{2} V_{\mathrm{dc}} \tag{21}$$

$$V_{\mathrm{Inva}} = \frac{(P_3 - P_6)}{2} V_{\mathrm{dc}} \tag{22}$$

$$V_{\mathrm{Inva}} = \frac{(P_5 - P_2)}{2} V_{\mathrm{dc}} \tag{23}$$

$$V_{\mathrm{Inva}} = \frac{(P_7 - P_8)}{2} V_{\mathrm{dc}} \tag{24}$$

Similarly the charging currents VInvad, VInvbd, VInvcd and Vinvnd on dc bus due to the each leg of inverter can be expressed as

$$I_{\mathrm{Invad}} = I_{\mathrm{Inva}}(P_1 - P_4) \tag{25}$$

$$I_{\mathrm{Invbd}} = I_{\mathrm{Invb}}(P_3 - P_6) \tag{26}$$

$$I_{\mathrm{Invcd}} = I_{\mathrm{Invc}}(P_5 - P_2) \tag{27}$$

$$I_{\mathrm{Invad}} = I_{\mathrm{Inva}}(P_7 - P_8) \tag{28}$$

The switching pattern of each IGBT inside inverter can be formulated on the basis of error between actual and reference current of inverter, which can be explained as: If $I_{\mathrm{Inva}} < (I^*_{\mathrm{Inva}} - h_b)$, then upper switch S_1will be OFF (P_1 =0) and lower switch S_4 will be ON (P_4=1) in the phase “a” leg of inverter. If $I_{\mathrm{Inva}} > (I^*_{\mathrm{Inva}} - h_b)$, then upper switch S_1 will be ON (P_1 =1) and lower switch S_4 will be OFF (P_4=0) in the phase “a” leg of inverter Where hb is the width of hysteresis band. On the same principle, the switching pulses for the other remaining three legs can be derived.

V. INTRODUCTION TO FUZZY LOGIC CONTROLLE

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 dc-to-dc converter system. 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 4 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

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definitions; a de-fuzzification interface which yields non fuzzy control action from an inferred fuzzy control action [10].

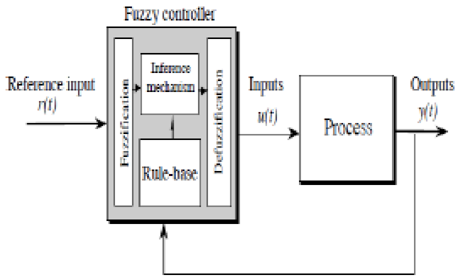

Fig.4. General structure of the fuzzy logic controller

The fuzzy control systems are based on expert knowledge that converts the human linguistic concepts into an automatic control strategy without any complicated mathematical model [10]..

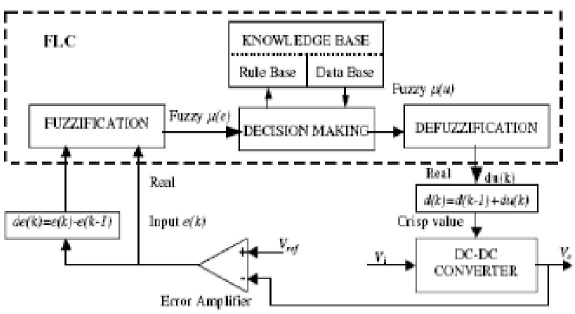

Fig.5. Block diagram of the Fuzzy Logic Controller (FLC) for proposed converter

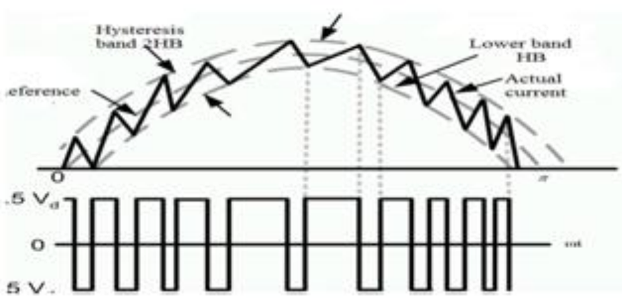

Fig.6. Hysteresis current Modulation

With the hysteresis control, limit bands are set on either side of a signal representing the desired output waveform [6]. The inverter switches are operated as the generated signals within limits. The control circuit generates the sine reference signal wave of desired magnitude and frequency, and it is compared with the actual signal. As the signal exceeds a prescribed hysteresis band, the upper switch in the half bridge is turned OFF and the lower switch is turned ON. As the signal crosses the lower limit, the lower switch is turned OFF and the upper switch is turned ON. The actual signal wave is thus forced to track the sine reference wave within the hysteresis band limits.

VI. MATLAB MODELEING AND SIMULATION RESULTS

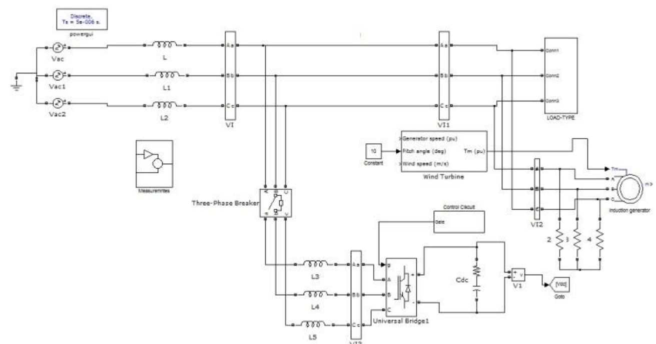

Fig.7 Matlab/Simulink of Proposed Statcom-Power Circuit

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.

Case 1: Proposed BESS-STATCOM with Conventional PI Controller

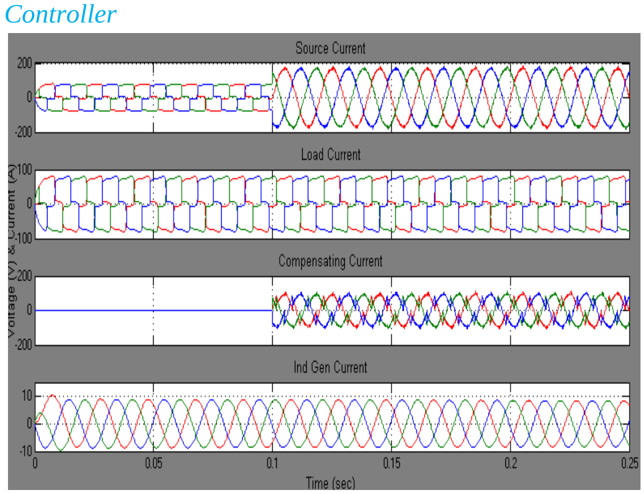

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Fig.8 Simulation results for Balanced Non Linear Load (a) Source current. (b) Load current. (c) Compensator Current. (d) Wind Generator (Induction Generator) Current.

Fig. 8 shows the source current, load current and compensator current and induction generator currents plots 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.

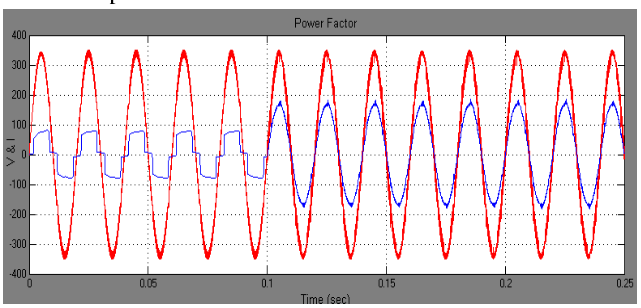

Fig.9 Power Factor For Balanced Non- Linear Load with Conventional PI Controller

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

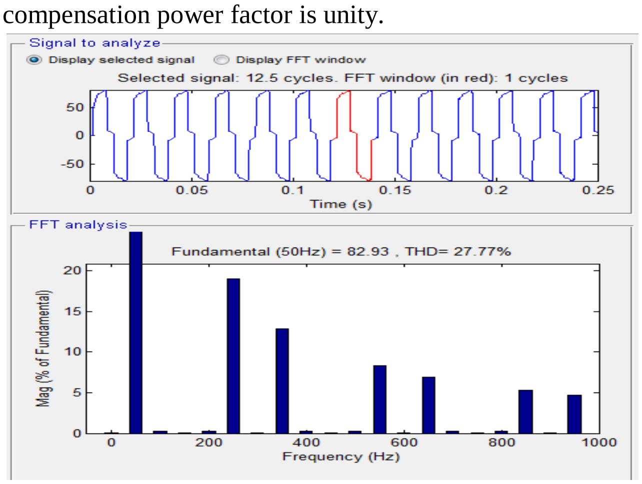

Fig. 10 FFT Analysis of Phase-A Source Current for Balanced Non-Linear Load without compensation scheme

Fig.12 shows the FFT Analysis of Phase-A Source Current for Balanced Non-Linear Load without any compensation, here we get 27.77%.

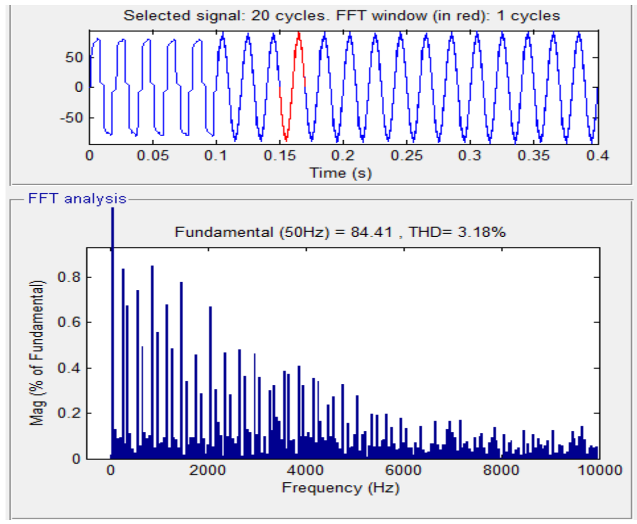

Fig. 13 FFT Analysis of Phase-A Source Current for Balanced Non-Linear Load

Fig.13 shows the FFT Analysis of Phase-A Source Current for Balanced Non-Linear Load, here we get 3.18%.

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

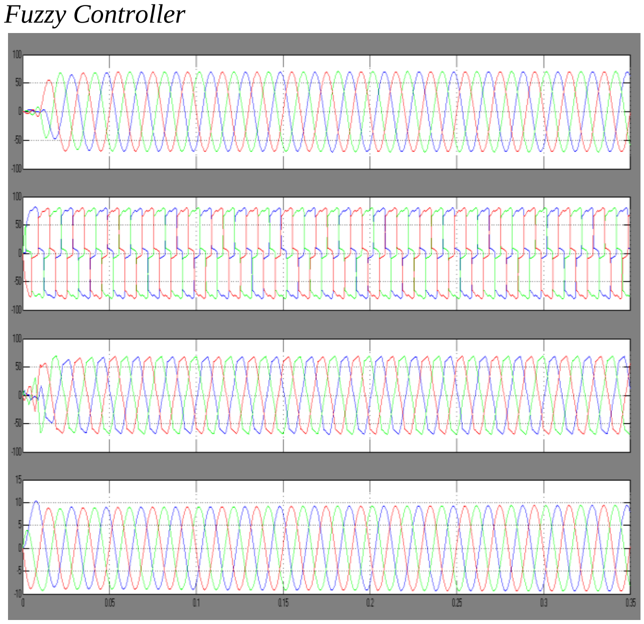

Fig.14 Simulation results for Balanced Non Linear Load (a) Source current. (b) Load current. (c) Compensator Current. (d) Wind Generator (Induction Generator) Current.

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Fig. 14 shows the source current, load current and compensator current and induction generator currents plots respectively with Intelligence based Fuzzy controller.

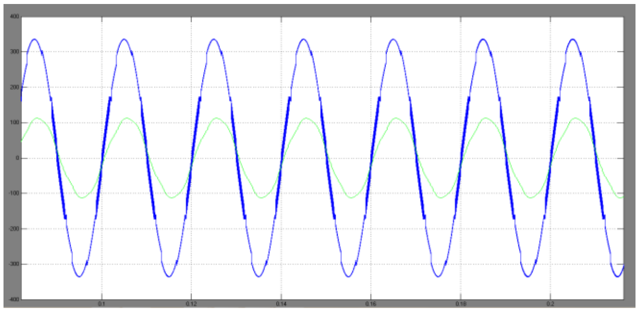

Fig.15 Power Factor for Balanced Non- Linear Load with Intelligence Based Fuzzy Controller

Fig. 15 shows the power factor it is clear from the figure after compensation power factor is unity.

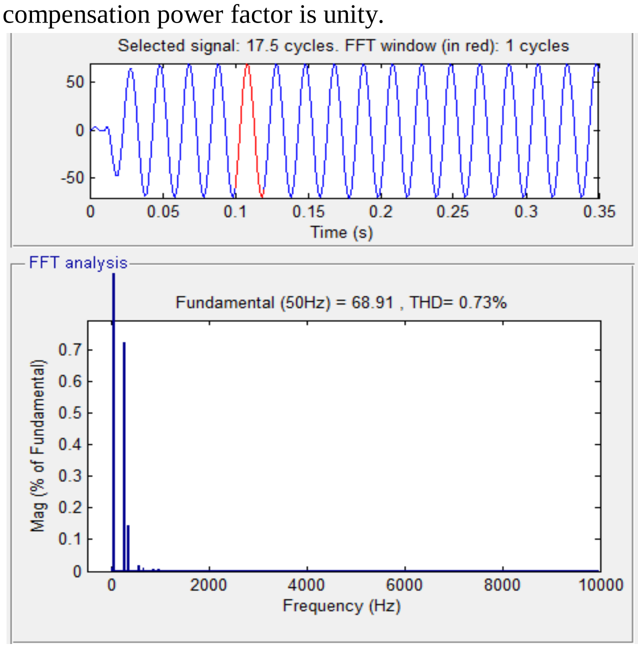

Fig. 16 FFT Analysis of Phase-A Source Current for Balanced Non-Linear Load with Intelligence based Fuzzy Controller

Fig.16 shows the FFT Analysis of Phase-A Source Current for Balanced Non-Linear Load, here we get 0.73%.

V. CONCLUSION

This proposed model is implemented using Matlab Simulink software and the obtained resultant waveforms were evaluated and the effectiveness of the system stability and performance of power system have been established. A novel STATCOM-based 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 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%.

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