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Quasi-Z-Source Based WECS for Suppression of Short Term Fluctuations

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***Abstract*—This paper proposes the design and simulation of Quasi-Z-source based wind energy conversion system for suppressing short term fluctuations. Quasi-Z-source inverter is a new promising power adaptation technology perfectly suitable for interfacing of renewable energy sources such as wind turbines, photo voltaic. The Quasi-Z-source network has the advantage of single stage conversion of Buck-boost function and non zero input current. This leads to reduced stress of the input voltage source. Normally to interface the energy storage systems like supercapacitors and battery banks to wind power systems, converters were used and this will introduce additional cost and power losses. Hence in this proposed method dual inverter topology and super capacitor bank were used to reduce the aforementioned drawbacks. A dual inverter consists of MAIN inverter which is connected to the coupling transformer and an auxiliary inverter, an energy storage system is interfaced with secondary inverter. So the overall system includes wind turbine, PMSG, DC-DC converters, three phase voltage source inverters, energy storage system and related power electronic devices. The Simulation results are presented to authenticate the effectiveness of the proposed system in suppressing short-term wind power fluctuations.**

Keywords—Quasi-Z-source inverter, Dual inverter topology, Energy storage system, MPPT, PMSG, Wind turbine, MATLAB/SIMULINK.

I. INTRODUCTION

Global Warming is one of the most decisive environmental exertion arising in the world, must be taken into observation. The emissions of greenhouse effect gases should be avoided [1]. However, the generated power from the renewable source is always fluctuating in nature due to an environmental status. To endorse renewable energy and compensate the fluctuating power an energy storage system is an effective solution. Among all renewable energy sources Wind power is the fastest growing renewable energy source due to its improving technologies and economical competitiveness. Generally, we can't able to predict the availability of wind energy at particular time. So the control also not an easy one like conversion from fossil fuels; because, wind energy underlies a conjectural fluctuating actions [2]. These fluctuations are the basis of vibrant power oscillations in the wind energy converter's power drain. They promulgate from the wind rotor to the connected electrical grid and cause precipitate damage in mechanical components, thermal overloads in electrical components, as well as voltage variations in the mains power supply. So to mitigate these fluctuations large batteries, flywheels, super capacitor banks are chosen as storage options due to the ability to directly specify a system with the necessary power and energy capacity. Interfacing converters are used to connect these energy storage devices with the wind energy systems. The interfacing dc–dc converter increases the system cost, power losses, and complexity, even if an optimized design is used. A direct integration method is introduced to overcome the aforesaid drawbacks. This paper, therefore, presents a direct integration scheme for energy storage system with the use of grid-side inverter. It utilizes the popular dual inverter topology, as shown in Fig. 1, where two inverters are coupled through a coupling transformer. The two inverters can be named as the main inverter and the auxiliary inverter in line with their modes of operation. A supercapacitor bank is directly connected to the dc link of the auxiliary inverter without the use of dc–dc converter. So, the proposed system facilitates full controllability over charging/ discharging currents and voltage of the battery [3].

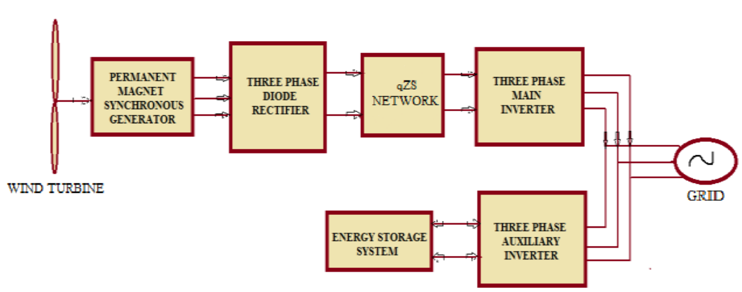

Fig.1 Block diagram of Quasi-Z-source based energy storage system for wind energy systems

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In this paper, the auxiliary inverter acts as active filter to reduce the harmonics produced by the main inverter and it operates at high switching frequency. The main inverter is a high power inverter, operates at low switching frequency and produces square wave output. Power fluctuations are periodic sags or swells which presents in the electrical current. Block diagram shown in figure1 consists of wind turbine coupled PMSG which is connected to dual inverter through a diode rectifier and an intermediate quasi network which is used to extract maximum power from wind turbine. Power electronic boundary devices are used for charging/discharging of energy storage system. The simulation results are presented to verify the efficiency of the system.

II. QUASI-Z-SOURCE BASED ENERGY STORAGE SYSTEM FOR WIND ENERGY SYSTEMS

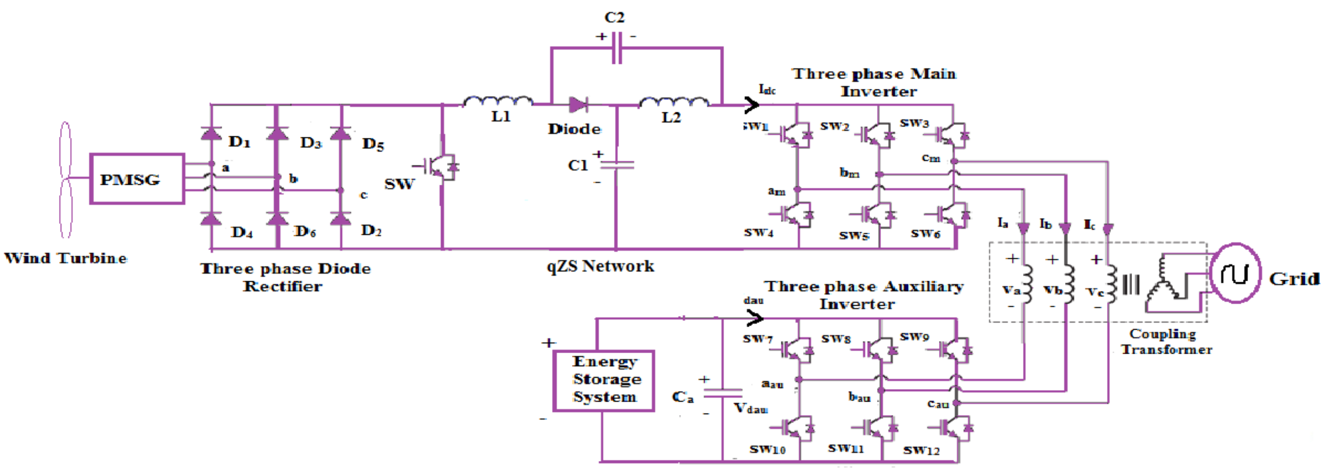

Fig. 2 Schematic diagram of proposed system

Figure 2 shows the schematic diagram of wind energy generating systems interfaced with energy storage systems. The proposed system consists of wind turbine coupled PMSG, a Diode bridge rectifier, Quasi-Z-source network, three phase inverters. The PMSG output is connected to main inverter through a diode bridge rectifier and qZS converter. The energy storage system is interfaced with the dc link of auxiliary inverter. The wind turbine is regulated by DC/DC qZS converter to a fixed dc output and is used to afford the power required by the grid. The energy storage system possibly a battery bank, fuel cell, super capacitor bank which is connected to an auxiliary inverter. The excess power can be directed towards the energy storage system, when the wind speed is high. Extensive research has been done on modulation and control of the aforementioned dual inverter topology, especially for motor drive applications [4]-[7]. They all have considered cases where fixed-integer dc-link voltage ratios are present. A pulse width modulation (PWM) proposal for this dual inverter is explained in [8] for 1:1 and 1:2 voltage ratios. Although a power sharing controller is anticipated for dynamically varying dc-link voltages, it also assumes that the identical dc-link voltage variations thus making the ratio to be 1:1.

A. *Modelling of wind turbine*

The wind energy in the wind turns two or three propeller-like blades connected to a rotor. The rotor is connected to the main shaft of the generator, which spins a generator to create electricity. The wind power can be calculated as follows

$$P_w = \frac{1}{2}\rho_{air} A_r V_w^3 C_p(\lambda, \tau) \quad (1)$$

Where, ρ_{air} is the air density,

V_w is the wind speed experienced by the rotor

A_r is the swept rotor area

C_p (λ, τ) is the power coefficient The power coefficient depends upon tip-speed ratio λ and pitch angle of blades τ.

$$\lambda = \frac{Rw}{v} \quad (2)$$

The torque on the rotor shaft, can be calculated from the power with the help of the rotational speed

$$T_A = \frac{Pw}{\omega} \quad (3)$$

$$T_A = \frac{Pw}{\omega} = \frac{1}{2\omega}\rho_{air} A_r V_w^3 C_p$$

$$T_A = \frac{1}{2}\rho_{air}\, \pi R^3\, V_w^2 \frac{Cp}{\lambda} \quad (4)$$

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The torque coefficient of wind turbine can be expressed as

$$C_T = \frac{C_p}{\lambda} \quad (5)$$

$$T_A = \frac{1}{2}\rho_{air}\,\pi R^3\, V_w^{\,2}\, C_T \quad (6)$$

B. Modelling of permanent magnet synchronous generator

Figure 3 shows a general dq-axis model of a synchronous generator. The field current in the rotor winding is represented by a constant current source If in the d-axis circuit, so as to model the rotor circuit. In the PMSG, the field winding can be replaced by permanent magnet and it can be modelled by an equivalent current If with a fixed magnitude.

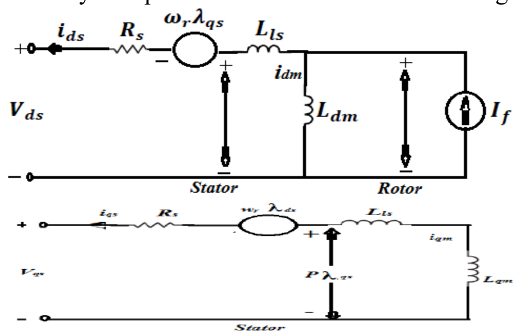

Figure. 3 dq-axis model of PMSG

To simplify the PMSG, the following mathematical manipulations can be performed. The voltage equations of synchronous generator can be written as

$$V_{ds} = -R_s\, i_{ds} - \omega_r\, \lambda_{qs} + p\lambda_{ds} \quad (7)$$

$$V_{qs} = -R_s\, i_{ds} - \omega_r\, \lambda_{ds} + p\lambda_{qs} \quad (8)$$

Where λds and λqs are the d-axis and q-axis stator flux linkages.

$$\lambda_{ds} = -L_d i_{ds} + \lambda_r \quad (9)$$

$$\lambda\ = -L_q i_{qs} \quad (10)$$

Where λr, is the rotor flux, and Ld and Lq are the stator dq-axis self-inductances, defined by

$$\lambda_r = L_{dm} I_f \quad (11)$$

$$L_d = L_{ls} + L_{dm} \quad (12)$$

$$L_q = L_{ls} + L_{qm} \quad (13)$$

Substituting and corresponding dλr/dt =0 for constant λr in the PMSG, we will have

$$V_{ds} = -R_s i_{ds} + \omega_r L_q\, i_{qs} - L_d\, p i_{ds} \quad (14)$$

$$V_{qs} = -R_s i_{qs} - \omega_r\, i_{ds} + \omega\lambda_r - L_d\, p i_{qs} \quad (15)$$

The electromagnetic torque produced of Synchronous generator can be calculated by

$$T_e = \frac{3p}{2}\,(i_{qs}\,\lambda_{ds} - i_{ds}\lambda_{qs}) \quad (16)$$

Substituting into 4, we have

$$T_e = \frac{3p}{2}\,[\lambda_r\, i_{qs} - (L_d - L_q)\, i_{ds}\, i_{qs}] \quad (17)$$

The rotor speed ωr is governed by the motion equation

$$\omega_r = \frac{P}{JS}\,(T_e - T_m) \quad (18)$$

To derive the SG model for dynamic simulation of synchronous generators, equation is rearranged as,

$$i_{ds} = \frac{1}{s}\,(-v_{ds} - R_s i_{ds} + \omega_r L_q i_{qs})/\, L_d \quad (19)$$

$$i_{qs} = \frac{1}{s}\,(-v_{qs} - R_s i_{qs} + \omega_r L_d i_{ds})/\, L_q \quad (20)$$

Stator voltages (dq-axis), rotor flux linkage λr, and the mechanical torque Tm are the input variables of PMSG, where as the output variables are the dq-axis stator currents, the rotor mechanical speed ωm, and the electromagnetic torque Te.

C. Three phase diode rectifier

A rectifier is an electrical device that converts alternating current (AC) into direct current (DC). This process is known as rectification. The diode rectifier converts the voltage from the generator to a DC voltage.

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D. Quasi-Z-Source Network

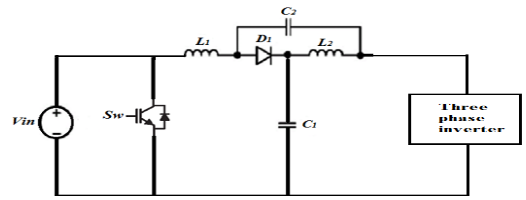

Fig. 4 Circuit diagram of Quasi-Z-source inverter

The voltage-fed quasi-Z-source inverter (qZSI) has been reported to be suitable for different renewable power applications (fuel cells, wind turbines, solar panels, etc.) because it has a distinctive capability of voltage boost and buck functions in a single stage. If obligatory, it can boost the input voltage by introducing a exclusive shoot-through switching state, which is the simultaneous conduction (cross conduction) of both switches of the same inverter's phase leg. This switching state is prohibited for the traditional voltage-source inverters (VSIs) because it causes the short circuit of the dc-link capacitor. The qZSI offers a special shoot- through states to store the magnetic energy in the dc-side inductors *L*1 and *L*2 without short circuiting the dc link capacitors *C*1 and *C*2[9]. So the increased magnetic energy in inductor leads to increase in output voltage . If the input voltage is as much as necessary, there will be an elimination of shoot-through states, and the qZSI starts to operate as a conventional VSI. The qZSI has the following advantages: Boost-buck function by the one-stage conversion; Excellent reliability due to the shoot-through withstanding capability; Low or no in-rush current during start up; Low common-mode noise [10].

E. Three phase dual inverter

The proposed three phase dual inverter consists of main and auxiliary inverter. Inverters are two-level voltage source converters. The converter is designed with six switches named as Sw1 to Sw6. The main inverter converts the fixed DC voltage to three phase AC with variable magnitude and frequency for an AC load. When the converter converts AC grid voltage with fixed magnitude and frequency to an adjustable DC voltage for a DC load, then it is called as auxiliary inverter. It is a bidirectional inverter it allows both rectification and inversion. The main converter is connected to an electric grid through a coupling transformer, and it delivers power generated from the generator to the grid. The Square wave outputs obtained from the main inverter gets smoothened by auxiliary inverter and it operates at low-frequency operation. Auxiliary inverter has high switching frequency and it acts as an active filter to smoothen the ripples and it uses Space vector modulation (SVM). Space vector modulation (SVM) is one of the real-time modulation technique and is used for digital control of the voltage source inverters. The active and zero space vectors represents the active and zero switching states. The six active vectors V1 to V6 forms a regular hexagon with six equal vectors. The zero vector V0 lies at the centre of the hexagon. The dual inverter scheme supplies the wind energy to the load, and energy storage system and reduces the power fluctuations in the grid side and makes energy balance.

Dual inverter based energy storage systems should reduce the power fluctuations in order to prove the effectiveness of the system and need to reduce the cost, power losses and complexity. If the energy storage systems integrated with dc-dc converter increase the cost and complexity. To reduce the above drawbacks, the synchronous reference frame proportional – integral (PI) controller is used here to provide the voltage references to the three phase inverters to obtain a zero steady-state error.

F. Supercapacitor implementation Issues

The main cause of power fluctuations will be the change of wind speed. Therefore, these fluctuations shows their influence on the capacity of energy storage system also. In order to go through this relationship, the wind is modelled with the dc quantity and a series of harmonics as in (21). In the following simulation, the wind speed fluctuation is assumed to be 20% of the mean value as in (22). The power captured from the wind can be expressed as in (23)

$$V_\omega(t) = V_{\omega 0} + \sum \Delta V_{\omega i} \sin(\omega_i t) \quad (21)$$

$$V_\omega(t) = V_{\omega 0}(1 + 0.2 \sin(\frac{2\pi}{T} t)) \quad (22)$$

$$P(t) = 0.5 \rho A C_p v_\omega(t)^3 \quad (23)$$

where v_ω is the instantaneous wind speed, $V_{\omega 0}$ is the mean wind speed of blades, $\Delta V_{\omega i}$ is the harmonic amplitude, ωi is the angular frequency ($f = 1/T = \omega/2\pi = 0.1 \sim 10$ Hz), ρ is the density of air, A is the swept area of wind turbine , and Cp is the coefficient of power conversion.

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III. POWER SHARING MPPT

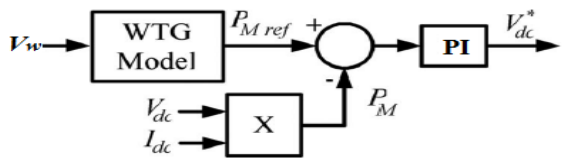

Fig.5 Block diagram of MPPT controller

The maximum power point of the wind turbine can indirectly be tracked by changing the main inverter dc-link voltage. The usual custom is to maintain this voltage at a constant level with the help of a dc-dc converter. Here the quasi-z-source network is placed between the main inverter and the wind turbine generator (WTG) system [2]. However, in the proposed system, the quasi-z-source network is used to vary the main inverter dc-link voltage and thus indirectly track the maximum power point of the WTG. The controller block diagram for maximum power point tracking (MPPT) is shown in Fig. 5. In this controller, the wind speed measured and the parameters of the turbine model are used to calculate the power reference for the quasi-z-source converter. The generated power from wind turbine is compared with the reference power, and the error is processed into a proportional–integral (PI) controller which generates a voltage reference for the quasi-z-source network. This voltage reference is used to produce the modulation index for the quasi-z-source network [9].

IV. MATLAB SIMULINK CIRCUITS

A. Simulink Model Quasi-z-source based energy storage system for wind energy systems

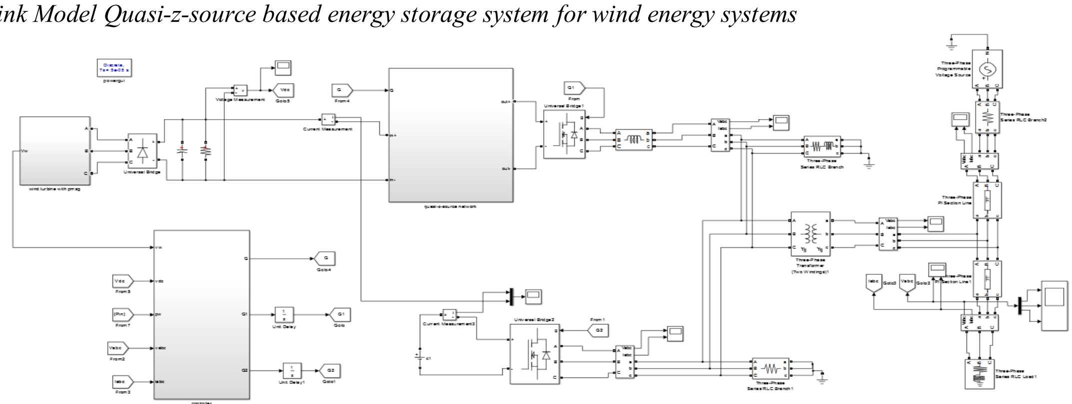

Figure. 6 Simulation model of Quasi-z-source based energy storage system for wind energy systems

The complete system is modelled on MATLABTM R2013a and SIMULINKTM. The simulation figure shows the Simulink model of Quasi-z-source based energy storage system for wind energy systems which consists of wind turbine, Diode rectifier, Quasi-z-source network, three phase dual inverters and battery. Battery is charged when the wind speed is maximum and it discharges when the wind speed is low. Battery is directly connected with the auxiliary inverter of dual inverter topology.

B. Simulink model of quasi-z-source network

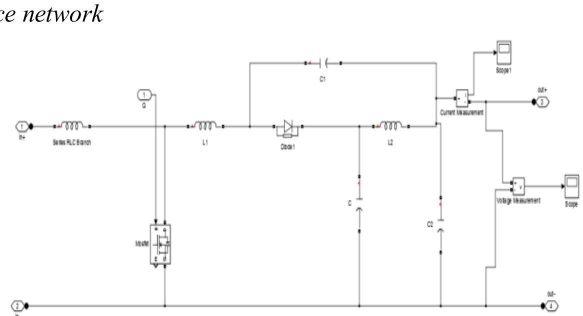

Fig. 7 Simulation Model Of Quasi-Z-Source Network

C. Wind turbine Simulink model

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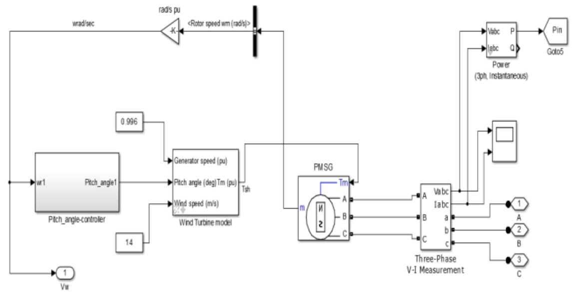

Fig. 8 Simulation model of wind turbine coupled PMSG

The wind speed taken is 14m/s and the mechanical output of wind turbine is coupled with the permanent magnet synchronous generator. The PMSG is 100KW machine whose rotor speed is taken out and it is compared with the input power to generate the voltage reference for Quasi-z-source network.

D. Simulink model of controller circuit of inverter

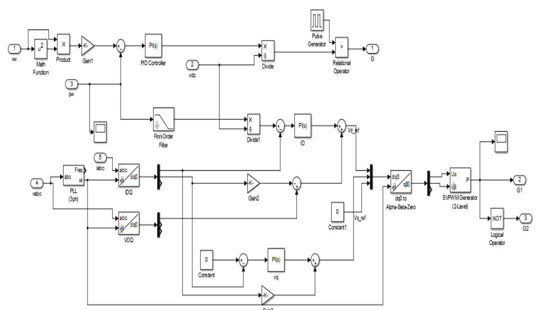

Fig. 9 Simulation of controller circuit of inverter

Figure 9 shows the control scheme of inverter. Inverter requires inner current controller and output power controller. The voltage and current from the grid connected load are converted into synchronous reference frame. The active power has been controlled by direct component of the inverter current and the reactive power has been controlled by the quadrature component of the inverter current. The reference active and reactive current components are compared with actual and the error is given to PI controller to produce voltage references.

V. MATLAB SIMULINK WAVEFORMS

The quasi-z-source network is used to boost the voltage upto 1.5 times higher than the traditional methods. With the wind turbine simulation model the wind speed is set to 14m/s and the pitch angle control as 25 deg. The input of PMSG is 100KW, the output voltage is 800V and the current is 55A. Figure 10 shows the waveform of voltage and current at the input side that is, after PMSG.

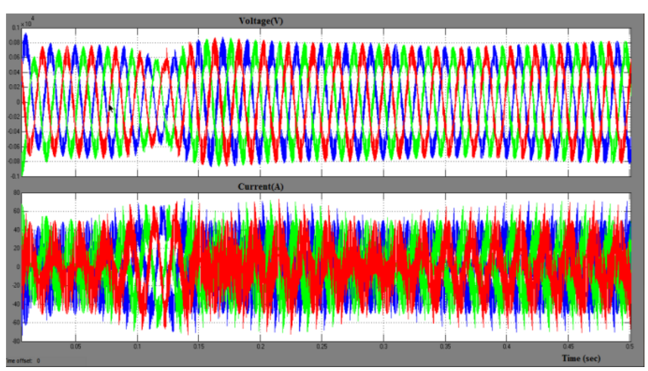

Fig. 10 Waveforms of voltage and current at PMSG

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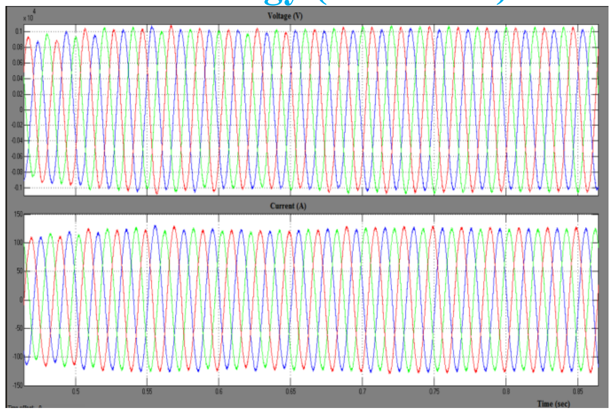

Fig. 11 Main inverter voltage and current

Figure 11 shows the waveform of main inverter voltage and current. Until battery charge is not given to the grid there are some disturbances in voltage after the battery charge given the voltage is constant. The output voltage is 1100V and current is 125A.

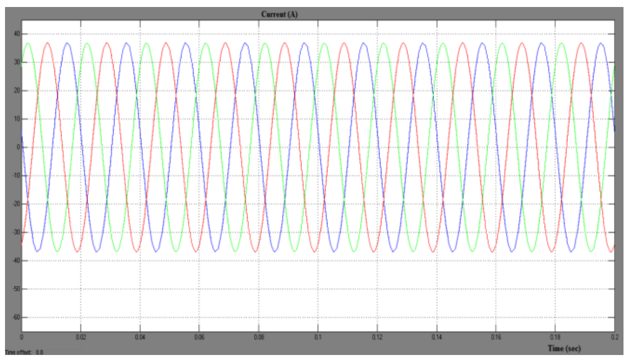

Fig. 12 Waveform of load current

The fig 12 shows the current waveform of grid connected load. A simple calculation would reveal that the corresponding input side fluctuation is about 66% while the output side fluctuation is less than 6.4%. This proves the efficacy of the proposed system in mitigating power fluctuations caused by wind changes.

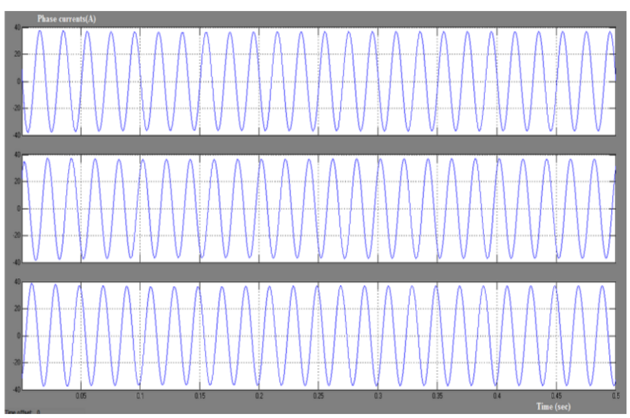

Fig. 13 Enlarged view of load current

The simulation diagram shows the wind energy conversion technique using dual inverter and energy storage system to reduce the short term fluctuations present in the output power generated by the Wind turbine coupled permanent magnet synchronous generator. It consists of large amount of fluctuations. This will be reduced by using aforementioned method in a efficient manner. For the first half time of the simulation battery will charge if the energy is excess and it discharges when the energy is in demand. The battery is charged at the rate of 50%. When there is reduction in wind power the stored energy from battery is

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discharged to the load which is controlled by MPPT.

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VI. CONCLUSION AND FUTURE SCOPE

In this paper, energy storage systems are interfaced with auxiliary inverter and power fluctuations are mitigated and also energy balance is made. By using supercapacitor bank as a energy storage device the power losses, cost, complexity are reduced. The reliability of the system is much improved. The simulation model of the proposed system was discussed in detail. Simulation results were presented to verify the efficacy of the proposed system in suppressing the short-term wind power fluctuations.

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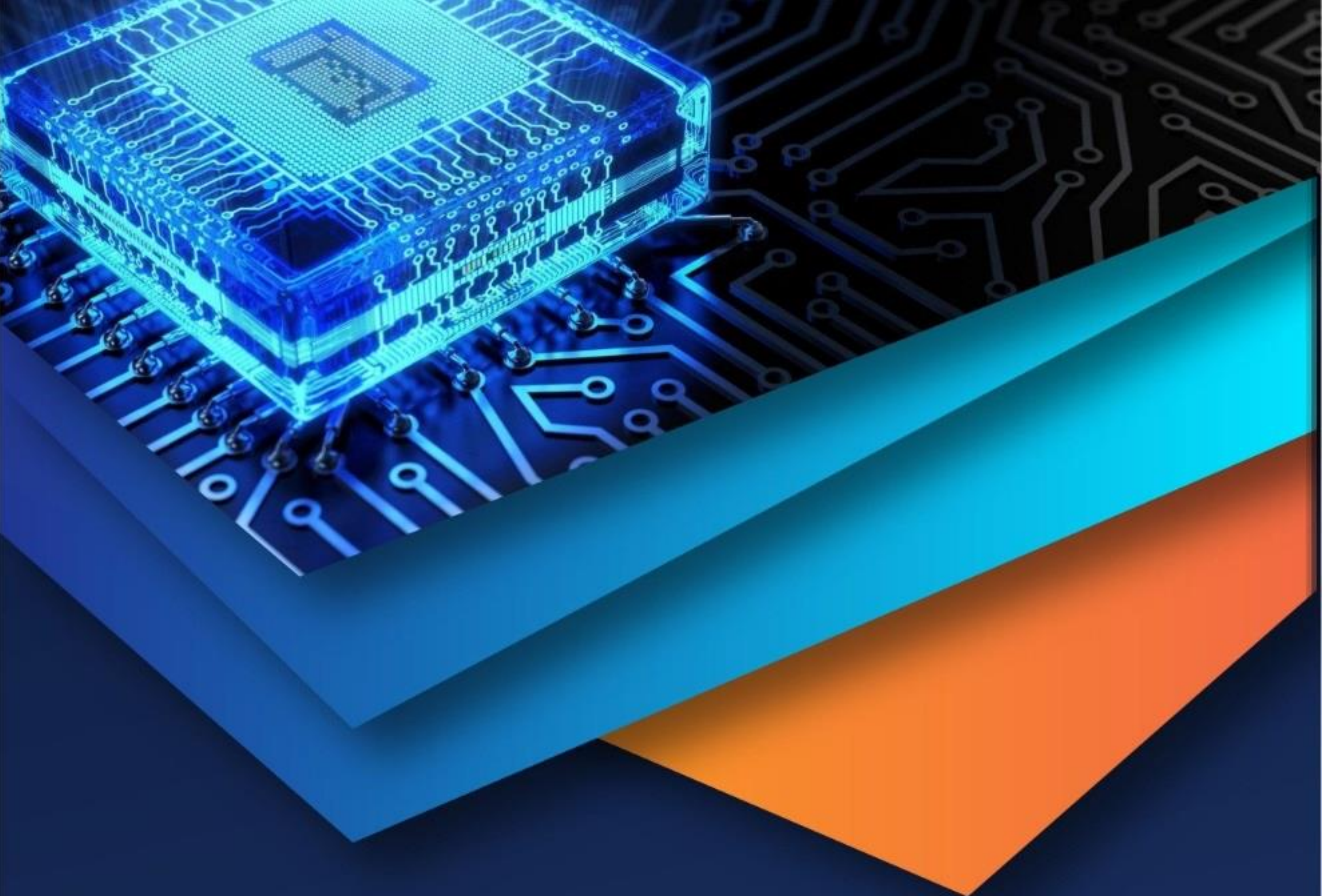

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