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Design and Simulation of Maximum Power Point Tracking based Wind energy Conversion system with Battery using Cascaded Multilevel Inverter

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ABSTRACT

This paper presents a maximum power point tracker for Wind Energy conversion systems equipped with Wind Turbine – DFIG, Battery and Cascaded Multilevel Inverter. The maximum power is extracted from the wind (MPPT-maximum power point tracking) using Incremental conductance method. Wind renewable energy source is integrated to the grid through utility grid side to improve power quality delivered to grid in terms of harmonics, by minimizing total harmonic distortion. The multilevel inverter reduces the harmonics compared to other power electronic converters. Wind energy system here is proposed with MPPT model, battery and cascaded multilevel inverter, simulated using MATLAB/Simulink. The power quality is maintained by harmonic reduction using 9 level cascaded bridge multilevel inverter through the simulation result.

Keywords: WECS, DFIG, MPPT, pitch control, CHB, harmonics

1. INTRODUCTION

Wind renewable energy source is in growing demands of the global power industry. It has totally about 336, 327MW installed power [1]. The evolution of the power electronic devices allows controlling variable wind speeds and designing small and large scale WECS [2]. Efficiency of wind turbines can be improved by using variable speed and extracting maximum power at different wind speeds. Every wind speed has a particular rotor speed leading to extract maximum power available known as MPPT [3]. Different types of generators are used such as WFIG, DFIG, SCIG, and PMSG. Among various concepts of variable speed, the wind turbine with DFIG is more advantageous than others [4]. In wind turbines the power converter is related to rotor power, i.e. with converter rating to be slightly low, approx. machine total power of 20%, which is economically higher than a fully rated converter configured in series. The reactive power controllability of wind turbines used with DFIG is same as that of synchronous generators. Numerous techniques for MPPT in Wind speed turbines are proposed in literature such as Perturb and Observe (P&O), Hill Climb search, Incremental Conductance (IC), Wind Speed Measurement, Power Signal Feedback, etc. P&O technique is more frequently used in Wind Energy Conversion Systems. In this paper Incremental Conductance (IC) [7] is used due to its advantage over P&O technique for its high sensitivity to variable wind speeds. Three-phase AC-AC converter is widely used i.e. rectifier-inverter structure pair [5]. But, different large storage components like intermediate DC-link, electrolytic capacitors, decreases system lifetime and increases overall size, weight and losses of the system leading to increase global system costs of the converter [6]. The cascaded multilevel inverter as replaced the above converters and have become globally competitive for these applications. It has drawn tremendous interest because of the greater

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requirement of high-power medium voltage inverters. It is composed of many power cells made of single-phase H-bridge. The single phase H-bridge cells, to achieve medium voltage operation and low or minimum harmonic distortion are arranged in cascade towards ac side. The cascaded H-bridge multilevel inverter has number of isolated dc supplies, Each H-bridge feeds power cell. Advantages are that, it operates at high voltage with stress per switching at lower voltage, higher efficiency and low electromagnetic interferences [17-18] etc. Nowadays, with the integration of renewable energy systems into the grid, emphasis on grid connected systems are increasing, leading to increased energy efficiency, system robustness, voltage support, energy sources diversification, transmission and distribution losses and system reliability. As wind distributed generation sources and their penetration level to the grid, thus, generation is our centre of focus. This paper shows that using incremental conductance method for MPPT, maximum power is extracted for wind energy system and stored using battery; it also sees that cascaded multilevel inverter helps in reducing the harmonics to reduce the problem of power quality in grid connected renewable energy sources.

2. WIND ENERGY CONVERSION SYSTEM

A WECS contains wind turbine, a generator as well as power electronic converters. The control characteristics of the generator and properties of wind-turbines mainly stall behaviour or blade-pitch control need to be collectively considered. In large wind turbine generators, DFIG (doubly-fed induction generator) is widely used as the variable speed induction machine [8]. The grid is connected with stator windings directly and rotor windings through an AC/DC/AC pulse width modulated (PWM) converter with wound rotor induction machine is connected to the grid [12]. The DFIG configuration is advantageous for its excitation power, which is 25% of the entire system power. Thus, it is easy to control the reactive power and to generate the active power with the help of rotor and the stator grid connected [13].

2.1. Wind turbine characteristics

The wind power is given as Pav, [14]; it is difficult to extract 100% wind power. Power coefficient C_p, is an index for a wind turbine conversion efficiency calculation. It can convert kinetic energy of wind less than 59.3% to mechanical energy [9]. Efficiency of a turbine, is found using TSR. The C_p blade pitch angle (β) and TSR (tip speed ratio, λ). The analytical function of power coefficient as calculated in [10]; the performance of wind turbine is defined in the C_p-λ curves. The blade pitch angle of different values, β angle is initialized to zero, for a constant blade pitch of a wind turbine. Then, C_p will be function of λ itself. Thus, maximum output power occurs at one point of tip speed ratio called TSR and is called the optimum TSR, represented as λopt[3]. To track MPP, at every wind speed, need to vary rotational speed to maintain TSR at its optimal value all the times, which is difficult at wind systems having fixed speed. But, variable speed turbines, change their rotational speed by instantaneous variations, with the help of suitable control system, and hence are able to maintain the optimum operation point TSR, λopt[11], achieving MPPT at different wind speeds.

2.2. Wind Maximum Power Point Tracking (MPPT)

2.2.1. Incremental Conductance Method

P = VI —— (1), P - power, V-voltage I- current, where, $\frac{dP}{dV} = \frac{dVI}{dV} = I + V\frac{dI}{dV}$ —— (2), Referring $\frac{dP}{dV}$ to $\frac{dP}{d}$ in [12] different conditions: If $\frac{dP}{dV} = 0$, here, and if $\frac{dP}{dV} > 0$, the left side of the point is where maximum Power Point is reached, similarly with the condition that $\frac{dP}{dV} < 0$, the side right point is maximum power point obtained. Whenever $\frac{dP}{dV} \neq 0$ appropriate control actions will be taken [15]. If $\frac{dP}{dV} = 0$ then $-\frac{I}{V} = \frac{dI}{dV}$ —— (3), Hence, $\frac{dI}{dV}$ is the incremental change in conductance.

Conductance will change with respect to the changes in the DC-DC converter duty cycle. When negative of instantaneous conductance equals the incremental change in conductance, the maximum power is extracted from wind by calculating optimal duty ratio as shown in Fig. 2. WECS implemented with MPPT control is that the continuous output of power is calculated by comparing above values; the dc-dc converter duty ratio, k is varied changing converter rectified output voltage V_{dc}, compared with the actual power output with previous cycle. If duty ratio, k is increasing in positive direction, the perturbation will continue for the next few cycles in the same direction which increases rotational speed, and the change decreases by reversing the direction of search. The optimum rotor speed for a particular wind speed is reached when the quantity $\Delta P/\delta\omega$ will be equal to zero. Thus, at this point MPP is tracked with operating point settling around [15, 16]. It assumes that when dV is positive, it is infinite. At this condition of the system, 50% approximately change duty ratio of the controller taking the correct direction. Otherwise, a reduced power at load is seen, but in the next cycle the system corrects observing the control result.

3. CASCADED H BRIDGE MULTILEVEL INVERTER

The cascaded H-bridge multilevel inverter is used for applications of high voltage for its modularity, reliability [17]-[18]. Its useful due to the high voltage generated from devices of low voltage rating in series. A high quality output voltage is produced from multiple voltage levels output. But switching devices gets increased and many different components added, due to which complexity increases and cost of the system.

4. PROBLEM OBJECTIVE

This paper tries to develop a model of grid connected renewable energy sources. The aim is to develop the model for wind energy system and connect it with a grid using dc-ac conversion via multilevel inverter. The objective is to design a micro grid consisting of wind with maximum power point tracking, battery and cascaded multilevel H bridge inverter. Connect the overall system to the grid, test the performance of system power quality transferred to the grid in the form of harmonics, and calculate the total harmonic distortion. Simulate overall wind energy system using MATLAB/SIMULINK.

5. SIMULATION MODEL USING MATLAB/SIMULINK

A case of six 1.5 MW wind turbines of wind farm connecting a 25 KV distribution system, power is exported through a 19 km 25 KV feeder120 KV grid. A 30 MW, 2MVAR motor load and of a 2MW resistance load to the same feeder is connected at bus B16. A 10 kW load on the 575 volt bus of the wind farm is connected.

5.1. Wind Turbine with DFIG Model:

Sub-synchronous speed at rotor is running with lower wind speed of 10 m/s and at high wind speed, it's running at super-synchronous speed. A single wind turbine block is created for wind farm of six turbines by considering the conditions: 1. Mechanical output power: 9MW, 2. Rated power of generator: 10 MVA.3. Dc bus capacitor: 6000μF, voltage regulation mode, reference voltage, as well as voltage drop is considered as 1 p.u as shown in Fig.1.

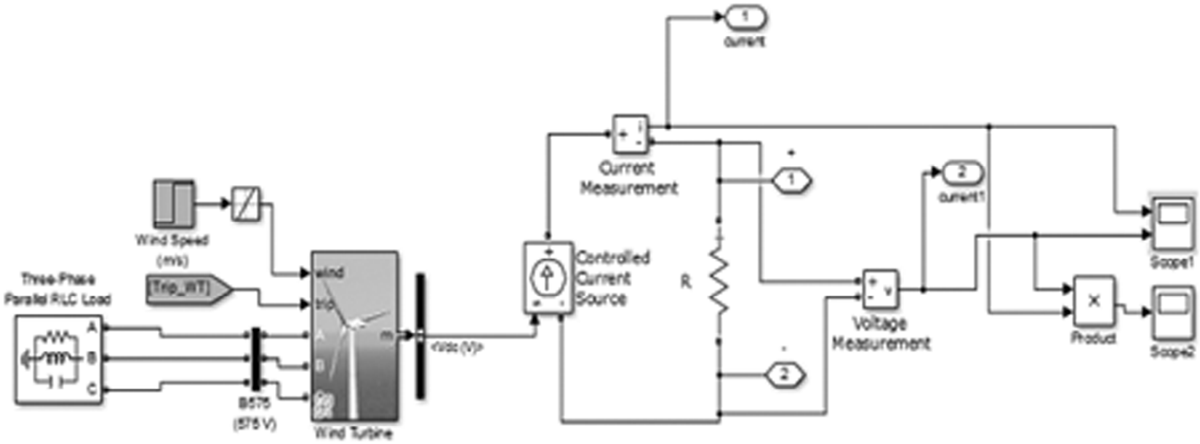

Figure 1: Wind Turbine –DFIG using Matlab/Simulink

5.2 Implementation of Incremental conductance method MPPT using MATLAB/SIMULINK

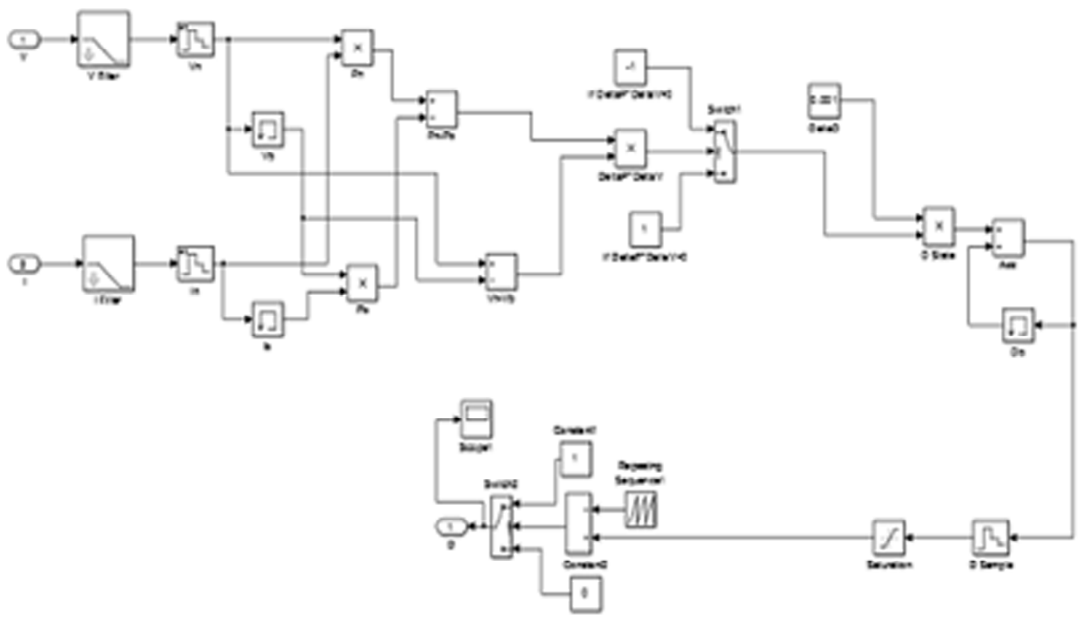

Figure 2: Incremental Conductance method of MPPT using Matlab/Simulink

5.3. Cascaded H Bridge Inverter Model

Individual DC voltage sources of V are used in the each module of H-bridge, in which the outputs are in series connected. From Eq. (1), the output voltage and number of voltage levels of output are calculated using Eq. (2). $v_{out} = \sum_{n=1}^{k} v_n = v_1 + v_2 + v_3 + v_4$ — (1) & N = 2k + 1 — (2), where k is the no. of DC voltage sources cells. In Eq. (1), v_n can be V, 0, or -V; i.e, v_{out} can produce -4V, -3V, -2V, -V, 0, V, 2V, 3V, 4V by many combinations of output voltage, thus modularity and simplicity can be obtained from the design. But, no. of switches and DC sources increases by 16 & 4 for 9-voltage output levels. As required for the research work, a 9 level cascaded multilevel is designed shown in Fig. 3.

5.3.1. Parameter Values

Frequency = 50Hz, T =1/f = 0.02 secs = 20 msecs, Largest pulse width = 0.001 secs, Phase delay - Ton = 0.01 sec, Toff = 0.001 sec, 9 level – Approximation of Sine wave, M = 2n + 1, N = no. of DC sources = 4, No. of Switches = 16, M = No. of levels = 9.

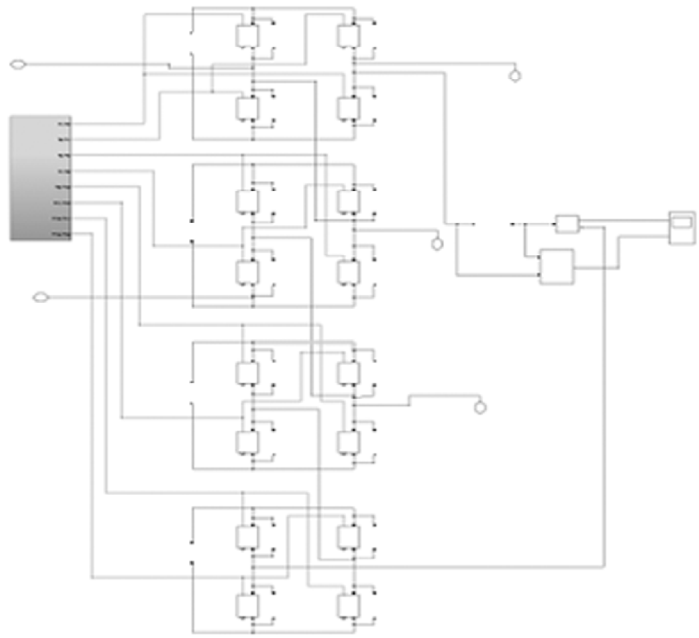

Figure 3: 9 level Cascaded H Bridge Multilevel Inverter

5.3.2. SPWM Technique for MLI

For pulse generation, a Sinusoidal pulse width modulation (SPWM) technique is implemented, where reference wave is sinusoidal (50 Hz) and carrier wave is high frequency (5 kHz) triangular wave. The

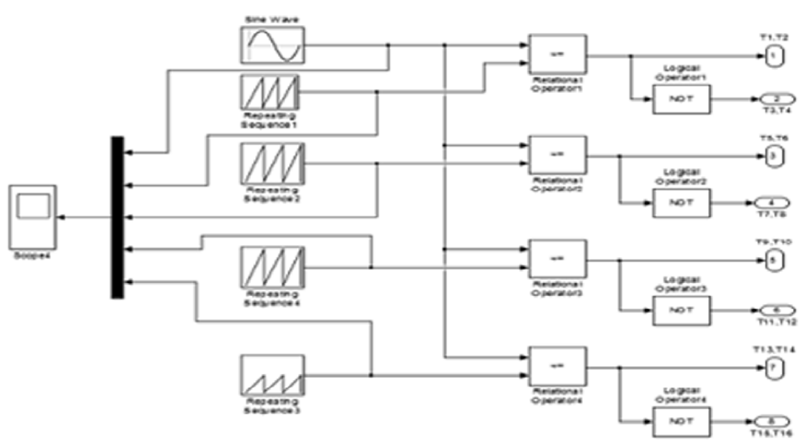

Figure 4: (a) SPWM pulse logic block

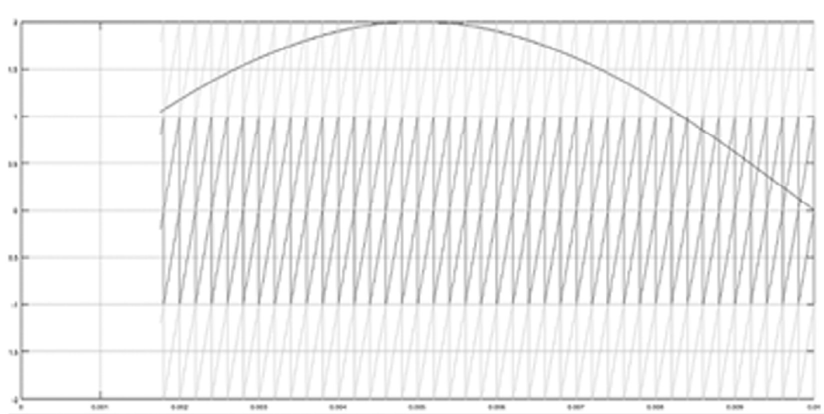

Figure 4: (b) methodology for generation of pulses.

comparison of both these waves gives rise to the pulses to trigger the switches. Level shifting SPWM technique is employed in order to reduce THD. Multiple carrier waves are compared with single reference wave with 2.0 modulation index and the pulses generated are as shown in Fig. 4 (a) & (b).

5.4. Wind MPPT with energy storage system & Cascaded H Bridge multilevel Inverter

The model for wind energy system connected to grid using dc-ac conversion via multilevel inverter, for designing a micro grid consisting of wind with maximum power point tracking, battery and cascaded multilevel H bridge inverter is as shown in Fig. 6.

6. SIMULATION RESULTS

6.1. Wind Turbine characteristics

The Fig. 6 shows output power of turbine (mechanical) Vs turbine speed, for speed varying between 5 to 16.2 m/s. The Double Fed Induction Generation controlled curve is shown in ABCD. Optimization speed of turbine is obtained at B and C point in the curve.

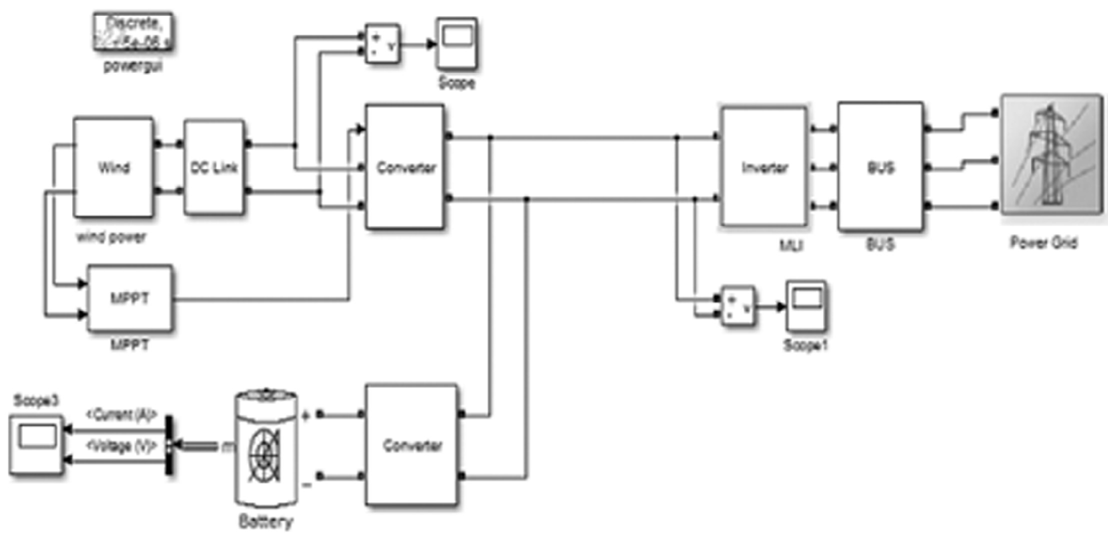

Figure 5. Wind with Energy Storage & modified Multilevel Inverter with Utility grid modeling using Matlab/Simulink

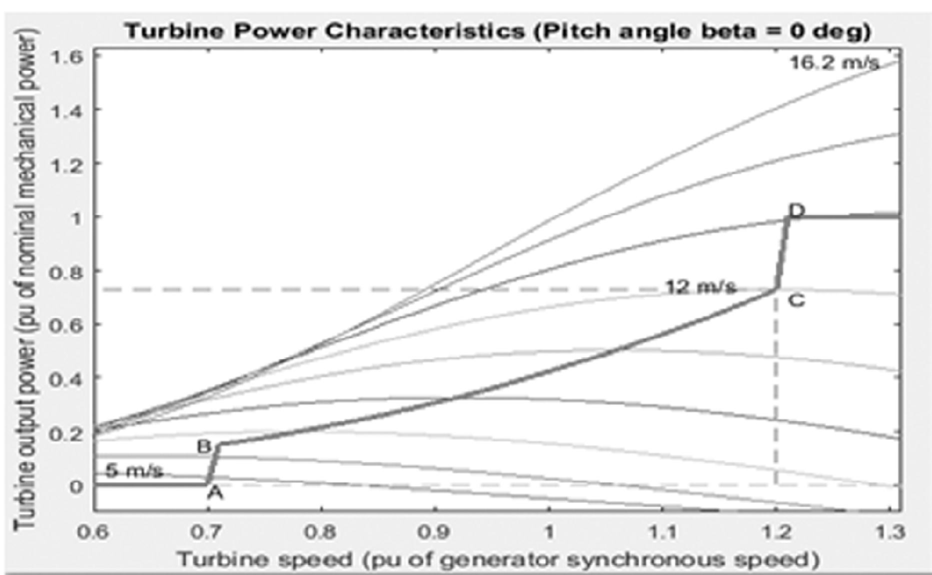

Figure 6: Wind Turbine characteristics

6.2. Wind Output Voltage and Current

As the case of 9 MW wind farm is considered, in which the output voltage, current and power is as shown in Fig. 7 & 8.

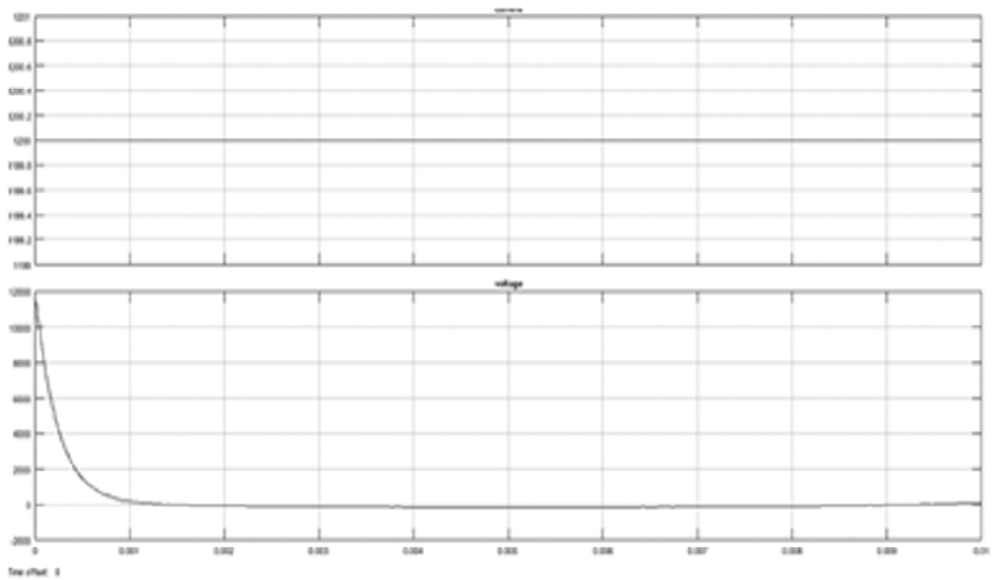

Figure 7: Wind output voltage, 12kV AC, Current 1.2kA

6.3. Wind Output Power

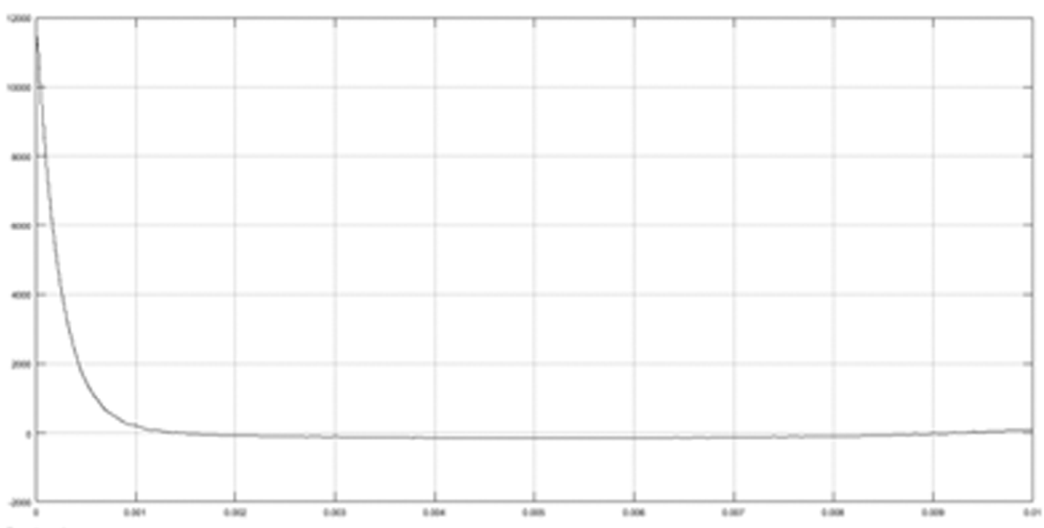

Figure 8: Wind output Power - 14MW

6.4 Battery Output

The battery output considered in the model is shown in Fig. 9.

6.5. CHB-Output voltage

Simulation of 9 level cascaded H bridge multilevel inverter pulse generated is shown in the Fig. 10

6.6. Grid Voltage

The entire system connected to grid is discussed and the grid voltage is shown in the Fig. 11

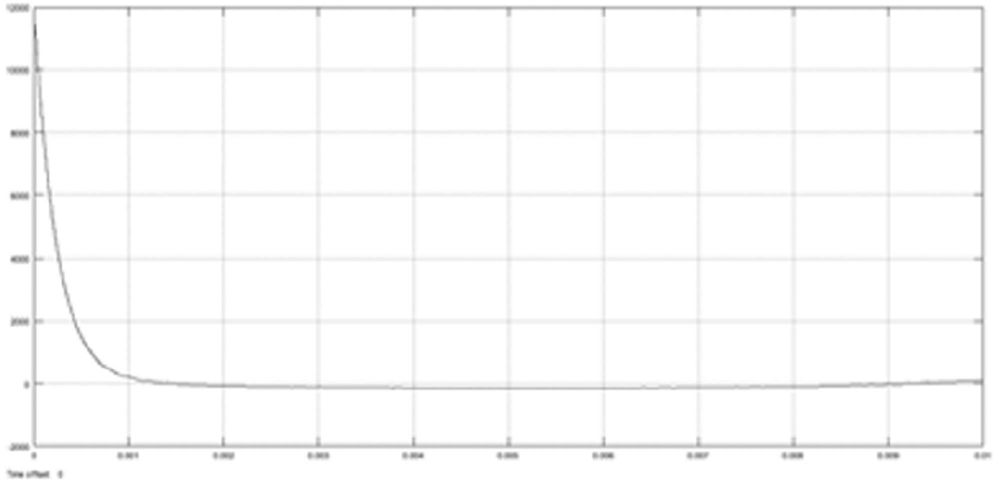

Figure 9: nominal voltage – 220V, rated capacity 100 Ah, fully charged voltage -259.15V

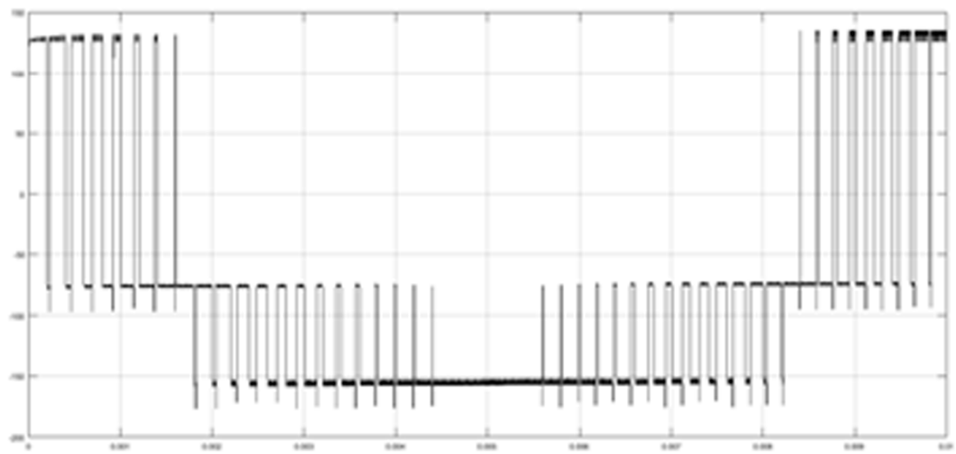

Figure 10: 9 level cascaded Multilevel Inverter output Voltage/current using Matlab / Simulink

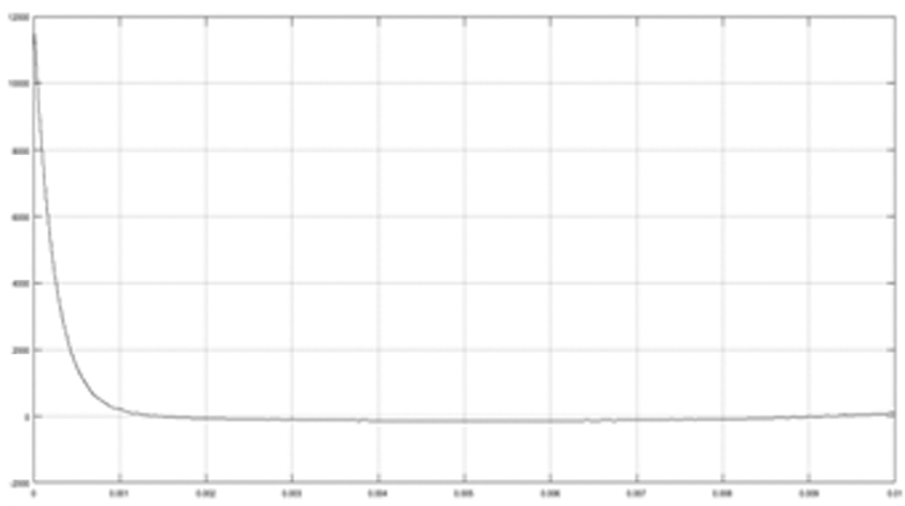

Figure 11: Grid Line voltage, Vab 169.70kV AC

6.7. Total Harmonic Distortion (THD)

Total Harmonic Distortion is calculated using FFT Analysis of MATLAB/SIMULINK MODEL for the CHB MLI grid connected for wind renewable energy is show in the Fig. 12

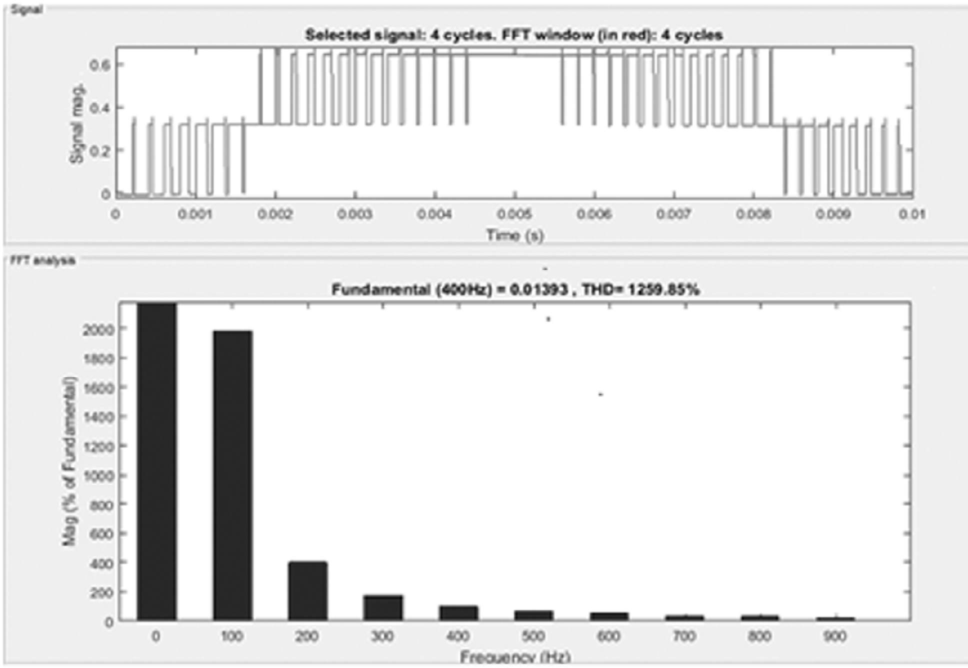

Figure 12: FFT Analysis

7. CONCLUSION

The paper researches that algorithm of Incremental conductance used for MPPT of wind generation systems, provides a better technique when high wind speed variations sensitivity is to be considered. The paper also uses power electronic converters eliminating capacitor banks for generation and absorption of reactive power. It can be seen that the cascaded multilevel inverter used for 9-level output voltage using SPWM technique reduces total harmonics distortion (THD).Wind generator model equipped with DFIG systems is simulated along with the boost converter, battery, MPPT control, cascaded H bridge model, using MATLAB/ Simulink. The DFIG improves torque pulsation, power quality and also efficiency. The result shows reduced harmonics using 9 level cascaded H-bridge multilevel inverter for grid connected wind energy systems and also extraction of maximum power using IC algorithm for wind energy resources. In future, research will be extended to the various modified MLI as well as other renewable energy sources.

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