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Modeling and Analysis of Cascaded H-Bridge Inverter for Wind Driven Isolated Self – Excited Induction Generators

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Abstract: This paper describes the simulation model and the harmonics analysis of multi level inverters fed RL load and induction motor load. The SEIG fed H- bridge multi level inverter (MLI) for variable speed wind energy conversion systems are considered for various stand alone applications. In this paper, the SEIG fed cascaded five levels inverter for induction motor load systems are clearly explained with the help of MATLAB / SIMULINK models. The generated voltage of the wind driven self – excited induction generator (SEIG) is mainly depending on the wind velocity fluctuations, appropriate capacitance values and load conditions. The five levels cascaded inverter has interface with the wind driven self – excited induction generator (SEIG). The variable magnitude, variable frequency voltage of the generator can be controlled by choosing the proper modulation index. The simulation and harmonic analysis of the proposed inverter will be discussed and the total harmonic distortion will be evaluated.

Keywords: Self – Excited Induction Generator (SEIG), Stand Alone Wind Energy Conversion System (SAWECS), Variable speed Wind Turbine, Impedance Source Inverter (ZSI) and Multi Level Inverter (MLI).

1. Introduction

Wind energy conversion scheme using a wind turbine driven SEIG, modern power electronic converter have been modeled, analyzed and implemented. The wind turbine generator system is producing an electricity from wind is the fastest growing energy technology in the world. Modern variable frequency drives operate by converting a 3Ø voltage source to DC using uncontrolled rectifier. The minimum and maximum values of capacitance required for self excitation have been analyzed previously [5] – [7].Especially in remote areas, Self-Excited Induction Generators are producing good electricity compared other generators. By using an advanced power electronic converters, the variable voltage variable frequency of the SEIG is converted into constant voltage and constant frequency. The squirrel cage induction generators have robust construction, lower inertia, and run-time cost, less maintenance cost and better transient performance. The generated voltage of the SEIG is mainly depends upon the excitation capacitance values, change in wind velocity and load conditions. The reactive power requirement by the induction generator can also be supplied by a group of capacitors. If the capacitance is insufficient, the induction generators will not build up voltage. The main draw of the induction generator is need of reactive to build up the terminal voltage.

2. Proposed System

A proposed ZSI based wind driven SEIG fed load is shown in Figure 1. The wind power generation system consisting of a wind turbine driven SEIG connected to the isolated load

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through an impedance source inverter. The power conversion efficiency of ZSI is improved compared to the traditional inverters for wind electric power generation. In traditional inverters, the upper and lower switches of each phase cannot be switched on simultaneously either by EMI noise. The output voltage of the ZSI is limited to either greater or lesser then the given input voltage. The variable output voltage from the induction generator is rectified and then inverted by using the proposed inverter. The ZSI can produce an output voltage greater than the input voltage by controlling the shoot through time T_o. This proposed scheme is used to improve the power factor and reduce harmonic current. The parameters used in the SEIG can be obtained by conducting no load test and short circuit test on the induction generator when it is used as an induction motor. The traditional tests used to determine the parameters are the open circuit test and the short circuit test. The induction machine used as the SEIG in this investigation is a three-phase wound rotor induction motor with specification: 415V, 7.5A, 3.7kW, 50Hz, and 4 poles.

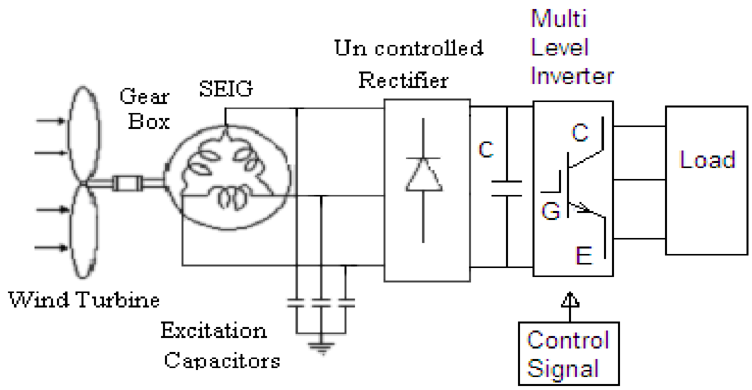

Figure 1. Proposed Impedance Source Inverter based Wind Power Generation System

A. Wind Turbine Characteristics

The common wind turbine with a horizontal axis is simple in working principle and it will produce a electric power economically. The wind turbine rotor drives a induction generator through a step up gear box.

The wind power density is given by

$$P_W = 0.5\ \rho\ Cp\ A\ V_w^3 \tag{1}$$

C_p is expressed as a function of λ

$$\lambda = \frac{R\omega t}{Vw} \tag{2}$$

Dimension less power co-efficient

$$C_p \quad C_p = 0.5\ [\frac{116}{\lambda_1} - 0.4\beta - 5]e^{\frac{-16.5}{\lambda_1}} \tag{3}$$

Where V_i is the hourly wind speed in kmph for i hour, N_m is the total hours in the specified period. The maximum theoretical power co efficient is equal to 0.593.

B. Self – Excited Induction Generator Modeling

The output power of the wind driven induction generator is determined by the operating speed. The per unit slip of the induction generator is lies between 0 and 0.05. The dynamic characteristics behavior of self-excited induction generator can be represented by the electromechanical equation derived in the synchronously rotating q-d reference frame [1][5].

The dynamic model of the induction machine is derived by using a two phase motor in direct and quadrature axes [3].

$$pi_{qs} = -K_1r_1i_{qs} - (i_{qs}/Cv_{ds} + K_2L_mw_m)i_{ds} + K_2r_2i_{qr} - K_1L_mw_mi_{dr} \quad (4)$$

$$pi_{ds} = (i_{qs}/Cv_{ds} + K_2L_mw_m)i_{qs} - K_1r_1i_{ds} + K_1L_mw_mi_{qr} + K_2r_2i_{dr} - K_1v_{ds} \quad (5)$$

$$pi_{qr} = -K_2r_1i_{qs} + L_1K_2w_mi_{ds} - (r_2 + K_2L_mr_2)L_2i_{qr} + (K_1L_1w_m - i_{qs}/ Cv_{ds} +)i_{dr} \quad (6)$$

$$pi_{dr} = -L_1K_2w_mi_{qs} + K_2r_1i_{ds} - (L_1K_1w_m - I_{qs}/Cv_{ds})i_{qr} + (r_2 + K_2L_mr_2)L_2i_{dr} + K_2v_{ds} \quad (7)$$

where

$$K_1 = \frac{L_r}{\left(L_sL_r - L_m{}^2\right)} \quad \text{and} \quad K_2 = \frac{L_m}{\left(L_sL_r - L_m{}^2\right)}$$

C. Un Controlled Bridge Rectifier

Three phase uncontrolled bridge rectifier is used to convert the variable voltage, variable frequency at the induction generator terminal into rectified dc voltage [3].

The output voltage is expressed as $Vr = (3\sqrt{2}/\pi)(\sqrt{3}/\sqrt{2}) * V_{ds} * n_i$ (8)

Input transformer's turn's ratio is 1:η. The series reactor (L) and shunt reactor (C) acts as an input filter. The current ripples and voltage ripples are reduced by using the above components [5].

D. Multi Level Inverters

The diode clamped multi level inverters are used to eliminate over voltage stress and reduce the switching frequency. By increasing the voltage levels of the inverter reduces the switching losses. To connecting the switching devices in parallel connections it leads to higher current levels. Multilevel converter topologies are based on this principle, and therefore the voltages applied to the devices can be controlled and limited. Then number of H bridges is formed as 4. The no of bridges is equivalent to (m-1)/2 where n is the no of levels (here 9) and the no of carrier waves for PWM control is equal to (m-1) overall for the positive and negative gate pulse generators. The modulation index of the inverter is $\overline{m} = \frac{\sqrt{3}}{2}m$. The range of the modulation index is $0 \le m \le \frac{2}{\sqrt{3}}$

3. Mathematical Analysis

There are many possible switching combinations that can synthesis stair case waveform for cascaded H- bridge proposed inverter. The number of switch combinations is proportional with the system's level (N). The relationship between the number of switch combinations and the system's level is expressed by [4]:

The number of output phase voltage levels is $M = \frac{N-1}{2}$ (9)

Number of switch combinations = 2^{N-1} (10)

For example, the number of switch combinations for five - level inverter is 2^{5-1} which is 16 different configurations. However, with the need of separate dc sources for real power conversions, the application of cascaded inverter can be somewhat limited.The carrier signal is a train of triangular waveform with frequency f_c and amplitude A_c.

Equations (6.3) defines the modulation index m_i for N-level inverter with M number of modules:

$$m_i = \frac{A_m}{\frac{(N-1)}{2}A_c} = \frac{A_m}{MA_c} \quad (11)$$

Therefore if *Ac* defined at a fixed p.u (1p.u), then m_i ranges between 0 and 1, while A_m ranges between 0 and M. The definition of the modulation ratio m_f for multilevel inverter is similar to the Conventional two-level output inverter, i.e.

$$m_f = \frac{f_c}{f_o} \quad (12)$$

Where *fc* is the frequency of the carrier signal and *fo* is the frequency of sinusoidal modulation signals.

Total harmonic distortion (THD) $\sqrt{\sum_{n=5,7,11..}^{49} \frac{V_n^2}{V_1}}$ (13)

For a cascaded inverter with m levels (including 0) per half-phase, the output voltage per leg is

$$V_{an} = V_{a1}+V_{a2}+V_{a3}+\ldots\ldots\ldots+V_{an-1} \quad (14)$$

The modulation index becomes $M = \frac{v_{cr(peak)}}{V_{an(peak)}} = \frac{v_{cr(peak)}}{(m-1)V_{dc}}$ (15)

4. Simulation results

In this chapter, the wind driven SEIG fed five levels cascaded five level inverter for stand alone wind power conversion scheme has been explained with the simulation results. The Figure 2 shows the simulation model of the SEIG fed H – bridge inverter with RL load. The H-bridge inverter sub system is shown in the Figure 3. The SEG voltage, rectifier voltage, inverter output voltage, current waveforms with RL load and induction motor load has been discussed with help of simulation results.

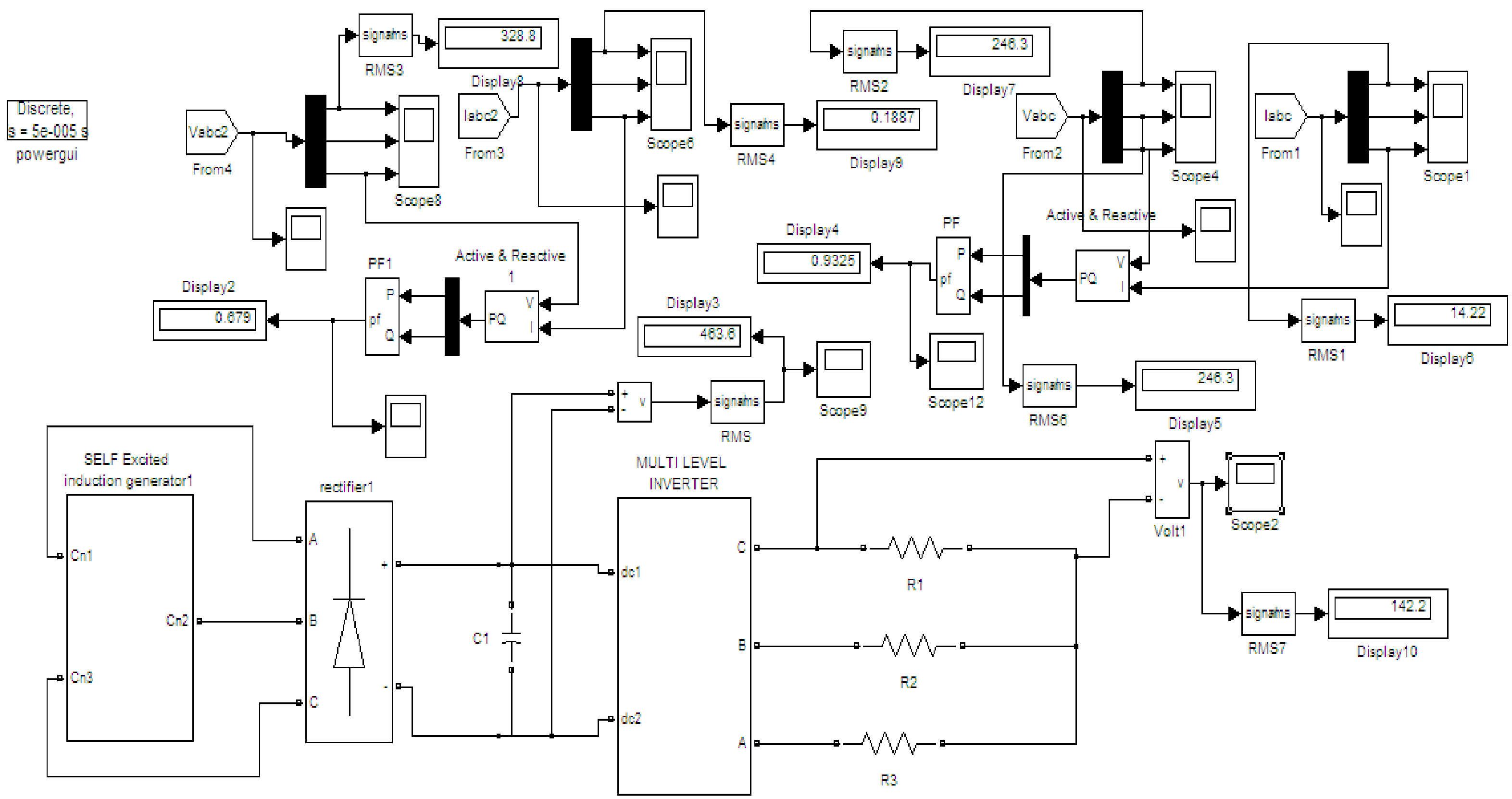

Figure 2. Simulation Model SEIG with Multi Level Inverter fed R – L Load System

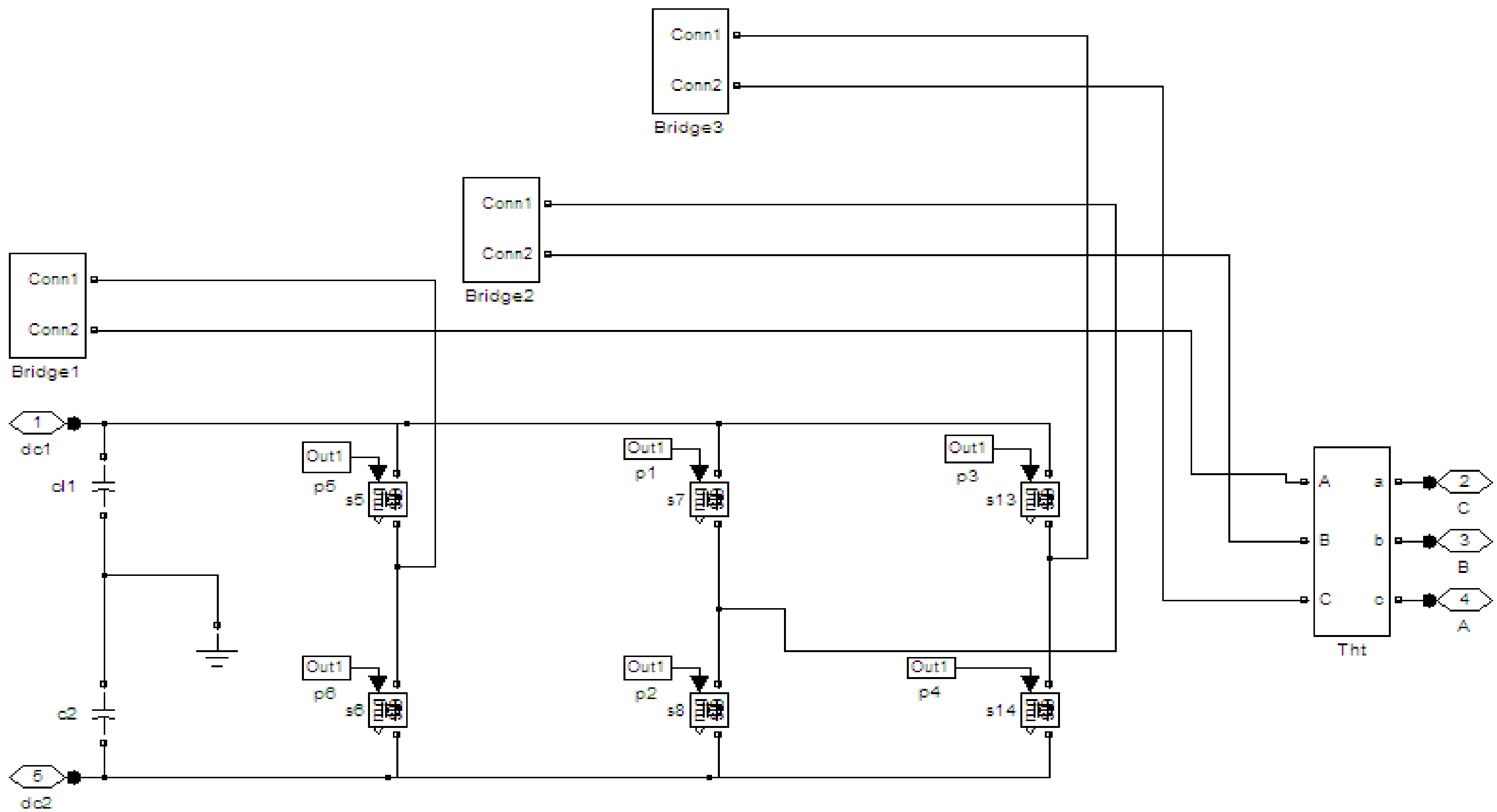

Figure 3. Multi Level Inverter Configuration

The generated voltage of the SEIG is shown in Figure 4. The generated voltage is 400 volts. This generated voltage is further rectified using the un controlled rectifier. The rectifier voltage is 392 volts. The output voltage of the rectifier contains more voltage ripples. The shunt capacitor is used to filter out the ripple contents and improve the voltage magnitudes.

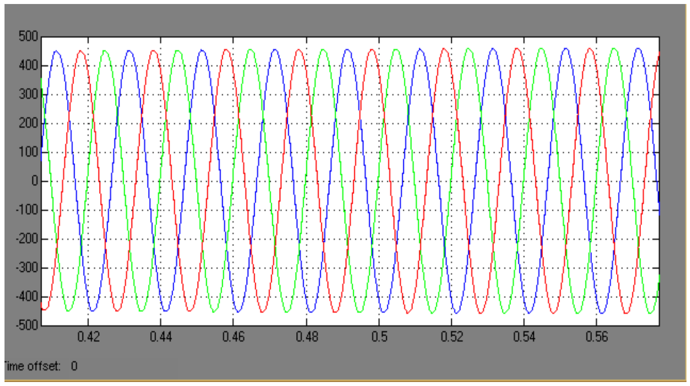

Figure 4. Generated Output Voltage of SEIG

The inverter contains no. of H – bridges. The no. of bridges is used to reduce the output ripples as well as improve the voltage magnitudes. Figure 5 shows the line voltage of 385 volts. The inverter current is shown in Figure 6.

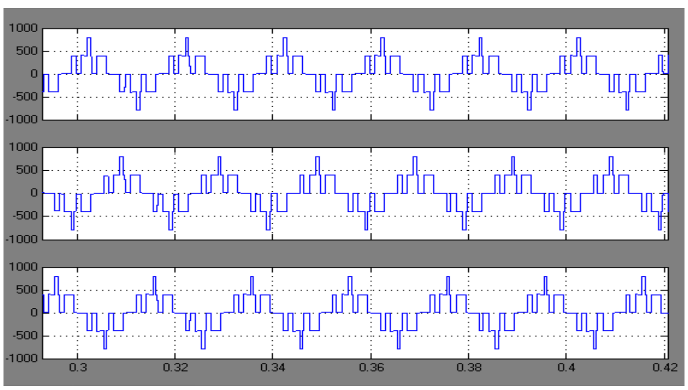

Figure 5. Line Voltage of the SEIG with Multi level inverter fed WECS

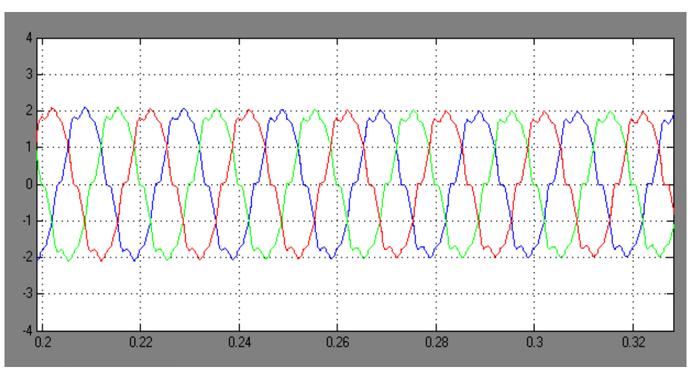

Figure 6. Line Current of the SEIG with Multi level inverter fed WECS

The total harmonic distortion is reduced in multi level inverters compared with the traditional inverter systems are shown in Figure 7. The THD value is 6.85%.

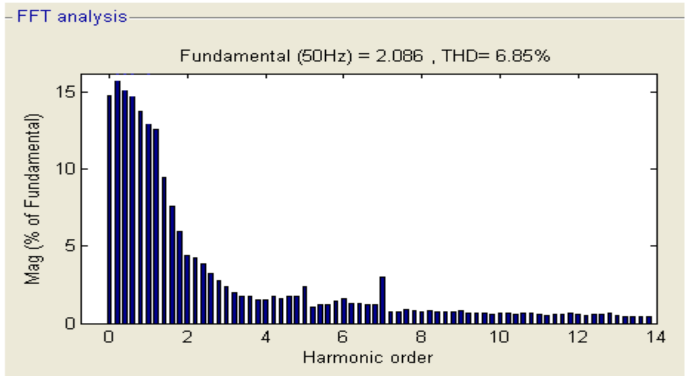

Figure 7. FFT Analysis of the SEIG with Multi level inverter fed WECS

To introduce an active harmonic elimination method to determine the firing angles for each level to eliminate any number of specific higher order harmonics of multilevel converters with unequal dc voltages. The output voltage of SEIG depends upon the wind velocity, self excitation capacitance value and wind flections. Excitation capacitors are used to reduce the reactive power burden of self excited squirrel cage induction generators. The variable magnitude and variable frequency output is given to the H bridge converters. This inverter produces a required voltage with low harmonic distortion compared with other traditional inverters. The Simulink model of SEIG fed five levels cascaded inverter with induction motor load system is shown in Figure 8. The generated voltage of SEIG is shown in Figure 9. The generator produces 385 volts which is fed back to the un controlled rectifier. The rectifier output voltage is 367volts. Figure 10 shows rectifier voltage applied to the inverter. In five level inverters are produce high voltage in the output terminal with less harmonic interruption. The phase voltage waveform of the cascaded five levels H – bridge inverter is shown in Figure 11. The inverter produces 360 volts in the output terminals. The equivalent circuit d-q model of the induction generator is helpful to analyze all its steady state characteristics. The parameters required for the modeling of the induction generators are determined by open circuit test (no load test) and short circuit test (Blocked rotor test). The parameters obtained from the above tests at rated values of voltage and frequencies are L_{ls}=L_{lr}=11.4 mh, L_m=180mh, R_s=1.7 ohm and R_r= 2.7 ohm. The induction motor runs reliable speed which is achieved the help of multi level inverters. The EMI noise also reduced by choosing the proper no. of bridges formed in the inverter circuitry. The proposed cascaded H-bridge multilevel boost inverter uses a standard three-leg inverter (one leg for each phase) and an H-bridge in series with each inverter leg which uses a capacitor as the dc power source. In this topology, the need for large inductors is eliminated. A fundamental switching scheme is used to do modulation control and to output five-level phase voltages. Experiments show that the proposed dc–ac cascaded H-bridge multilevel boost inverter without inductors can output a boosted ac voltage. The modes of operation are explained with the help of single phase H-bridge bridge inverter. Bridge inverter is called as H-Bridge Inverter. It is used to convert DC voltage in to AC voltage. It is one type of Multilevel inverters. Cascade multi level inverter has the simple configuration compare than other multi level inverters. The H-bridge inverter is connected with the supply voltage of V_{dc}. In these H-bridge consists of 6 switches. The controlled output voltage of the inverter is mainly depends upon the switching states. The output voltage of the inverter is controlled by fixed pulse width modulation technique. The H-bridge inverter can be operates at 5 different modes of operations

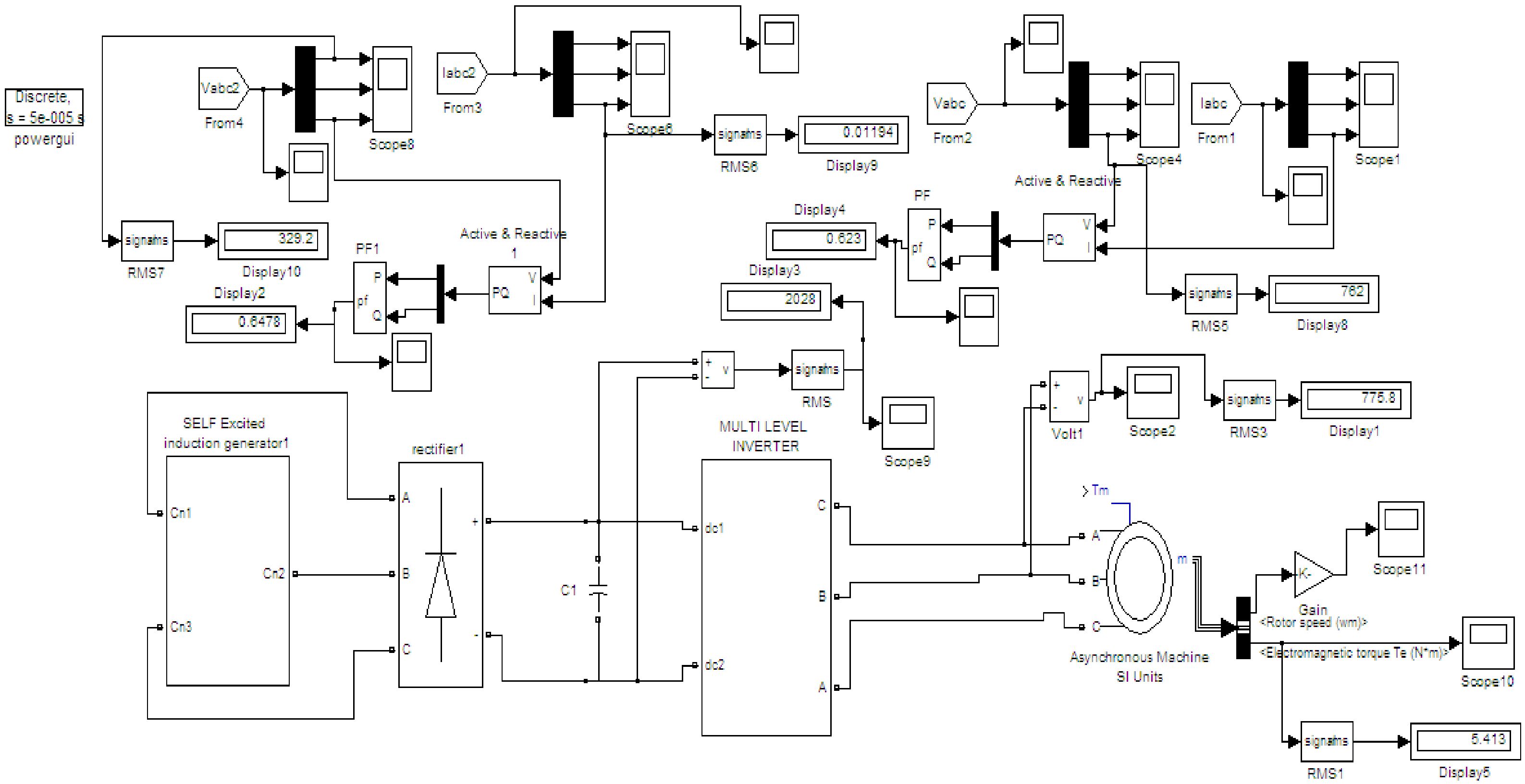

Figure 8. SEIG fed five level H- Bridge Inverter with Induction motor load

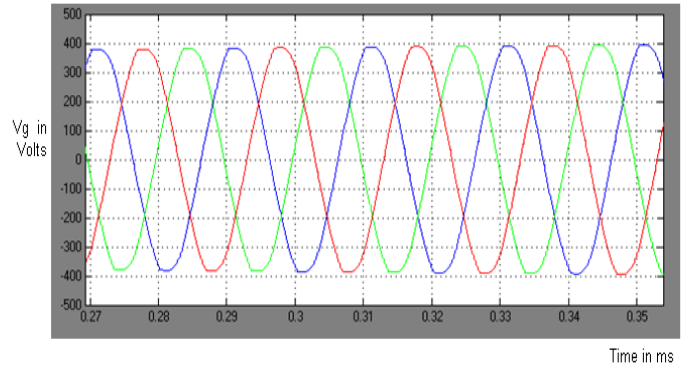

Figure 9. SEIG Generated Voltage

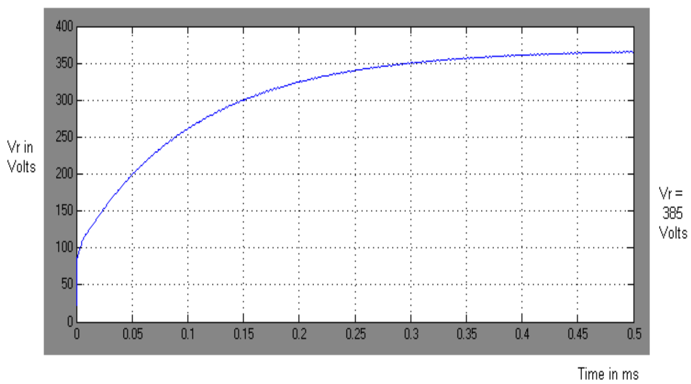

Figure 10. Rectifier Voltage

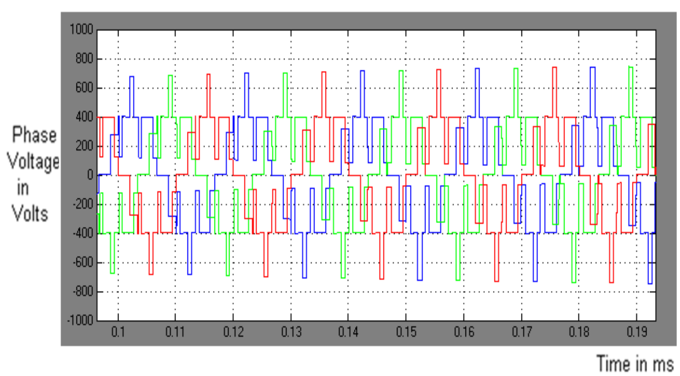

Figure 11. Phase Voltage Waveform

The cascaded H – bridge inverter fed induction motorload system have better performance compared with the flying capacitor multi level inverter and diode clamped multi level inverter fed system. The circuit complexity has been reduced for selecting cascaded H- bridge multi level inverter system.

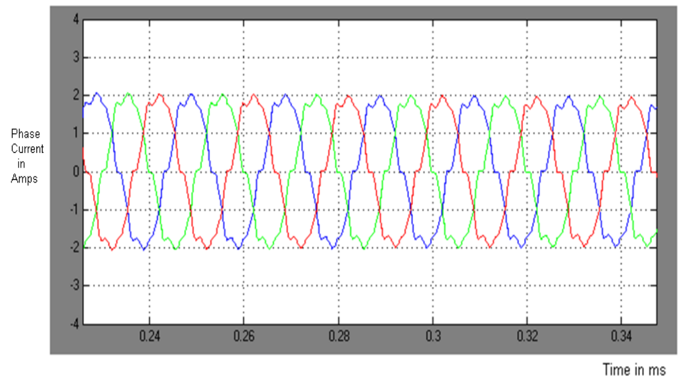

Figure 12. Line current Waveform

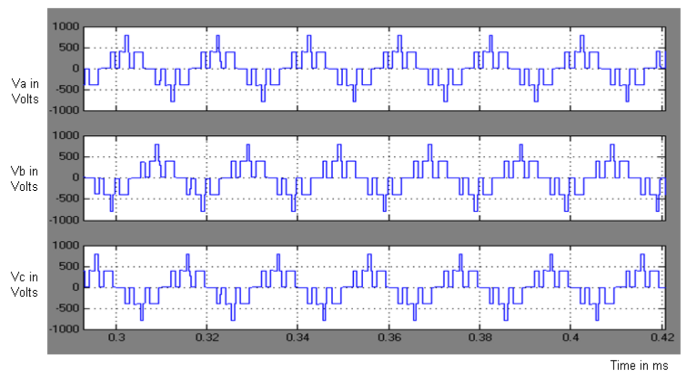

Figure 13. Line Voltage Waveforms

The line voltage of the five level inverter is 358volts which is shown in Figure 13. The line current applied to the induction motor load is 3.5 amps which is shown in Figure 12.

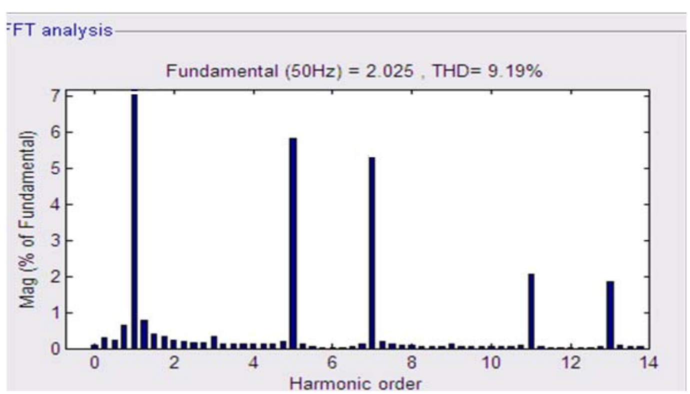

Figure 14. Harmonic Spectrum

The load voltage of the proposed inverter fed system mainly depending upon the load inductance value. The harmonic spectrum of the five levels inverter is shown in Figure15. The total harmonic distortion is increased which is mainly depends upon the load inductance values.

5. Conclusion

The modeling and simulation analysis of wind driven SEIG fed cascaded five level inverter based SAWECS results are tested with the load resistances and induction motor load. The SEIG in its no load condition generated a phase voltage of 440 volts at a speed of 1734 rpm. For a wind velocity of 11 m/s, the proposed inverter produced an output voltage of 385 volts were obtained for resistive load of 60Ω connected with SAWECS. The required output voltage was obtained for a wind velocity range of 11m/s. The inverter output voltage 360 volts and 3.5 amps current were maintained constantly in its open loop condition, when the wind velocity of 11 m/s. From the FFT analysis it is also observed that PWM generates less harmonic distortion (9.19 %) in the output current and more efficient use of inverter voltage and hence results in improved load performance.

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