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Cascaded H-Bridge Inverter for Wind Driven Isolated Squirrel Cage Induction Generators

G. Manohar[1] and K. Chiranjeevi[2]
[1]Assoc. Professor, CVR College of Engineering/EEE Department, Hyderabad, India
E mail: manohar.gangikunta@gmail.com
[2]PG Scholar, CVR College of Engineering/ EEE Department, Hyderabad, India
E mail: chiru.maheshwaram.019@gmail.com

Abstract: **This paper describes the simulation and harmonics analysis of cascaded five-level H-bridge inverters fed induction motor load drive for islanding mode applications. The self – excited induction generator (SEIG) fed H-bridge Multi-Level Inverter (MLI) for wind energy conversion systems is chosen for several islanding mode applications. In this paper, the SEIG (for standalone systems) fed cascaded five level inverter for induction motor load applications are clearly explained with the help of MATLAB / SIMULINK models. The generated voltage of the wind driven SEIG is mainly depending on the wind velocity fluctuations and appropriate load conditions. The five level cascaded inverters have interface with the wind driven SEIG. By choosing appropriate value of Modulation Index (MI), the variable voltage and variable frequency of the generator can be finely controlled. The simulation and harmonic analysis of the proposed inverter will be discussed, and the total harmonic distortion of stator current for different modulation index at different switching frequencies are evaluated and the speed and torque of induction motor for different load torques are plotted.**

Index Terms**:** ***Self*** **– Excited Induction Generator (SEIG), Variable speed Wind Turbine, Multi Level Inverter (MLI), Induction Motor (IM), Modulation Index (MI).**

I. INTRODUCTION

Wind energy conversion scheme the use of a wind turbine driven SEIG, modern electricity virtual converter was modelled, analysed and completed. Generation of electrical energy from the wind the wind energy is gaining tremendous importance internationally in this decade. Modern variable frequency drives operate with the aid of changing a 3-phase voltage deliver to DC the usage of out of control rectifier. The values of capacitance required for self-excitation were analysed formerly [1]– [2]. Especially in far flung areas, Self-Excited Induction Generators are generating proper energy in comparison with specific generators. Employing static power electronic converters, the variable voltage and variable frequency of the SEIG is converted into desired voltage and standard frequency. The wind turbines employed in wind generation system have strong production, lower inertia, and run-time charge, a good deal much less preservation fee and better short universal performance.

If the capacitance is insufficient, the induction generators will not be able to construct the voltage. In order to build up the terminal voltage, a constant speed wind turbine tied induction generator requires reactor power support which is generally provided by capacitor banks of large capacity. Wind turbines are produced in a wide scope of vertical and level pivot. Less capacity wind turbines are utilized for simple applications, such as battery charging for power traffic cautioning signs.

Turbines with moderate capacity can be exploited for making assurances to a domestic power supply while vending extra energy back to the utility provider through the electrical network. Wind turbines with a capacity of 5MW per unit are available in and used by the utilities today. Wind turbines can either can be coupled to SEIG or Doubly Fed Induction Generator (DFIG). Requirement of reactive power for building the terminal voltage is major limitation of constant speed induction generators.

II. PROPOSED SYSTEM DESCRIPTION

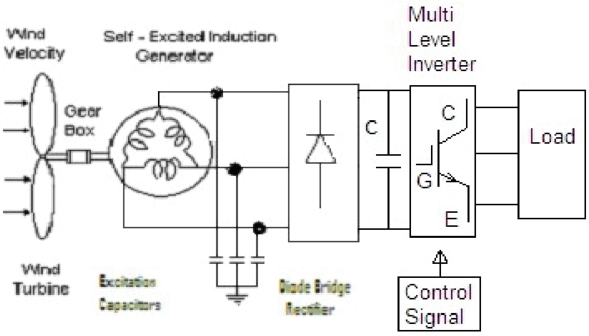


Figure 1. Proposed Impedance Source Inverter based Wind Power Generation System.

The proposed impedance source inverter-based wind energy driven SEIG encouraged burden is shown in the “Fig. 1,”. The SEIG is driven by the wind turbine and output of the induction generator is fed to five-level cascaded H bridge inverter which in turn provides the terminal voltage to induction motor. The power transformation proficiency of ZSI is improved in contrast with the conventional inverters for wind electric power application. The desired reactive power of the SEIG is provided by the three-phase capacitor banks connected at the output terminals of the SEIG. The variable yield voltage from the acceptance generator is amended and after that modified by utilizing the proposed inverter. The ZSI can be made to operate to deliver output voltage greater than the voltage fed to it by effectively controlling the shoot through time. Overall power factor of the system can be improved by the proposed method with an additional benefit of reduced Total Harmonic Distortion (THD) in the stator current.

A. Wind Turbine Equations and characteristics

Due to simple construction and working principle, a horizontal axis wind turbine is preferred in wind energy systems and it will produce electric power economically. The wind turbine rotor drives the induction generator through a step-up gear box.

The mechnical power output of wind turbine is given by

$$P_W = 0.5\rho C p A V w^3 \tag{1}$$

where A is the area in sq. meters
V_W is the Velocity of the wind in m/s
Cp is power co efficient and is expressed as a function of λ

$$\lambda = R\omega_t / V_W \tag{2}$$

$$C_P = 0.5((116/\lambda_1)\text{-}0.4\beta - 5)\ e\text{-}^{16.5/\lambda 1} \tag{3}$$

where V_w is the wind speed estimated on hourly basis and it's units are kmph, 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 Modelling

Induction generators are broadly used, specifically polyphase induction cars that are frequently utilized in industrial drives. When the rotor of the induction machine is coupled to wind turbine and driven at a speed greater than synchronous speed, the induction machine works as induction generator generating electricity from mechanical energy. The modelling of the induction generator in d-q axis is described by the following equation [3].

$$\begin{aligned} pi_{qs} = &-K_1 r_1 i_{qs} - (i_{qs}/Cv_{ds} + K_2 L_m w_m) i_{ds} + K_2 r_2 i_{qr} - \\ &K_1 L_m w_m i_{dr} \end{aligned} \tag{4}$$

$$\begin{aligned} pi_{ds} = &(i_{qs}/Cv_{ds} + K_2 L_m w_m) i_{qs} - K_1 r_1 i_{ds} \\ &+ K_1 L_m w_m i_{qr} + K_2 r_2 i_{dr} - K_1 v_{ds} \end{aligned} \tag{5}$$

$$\begin{aligned} pi_{qr} = &-K_2 r_1 i_{qs} + L_1 K_2 w_m i_{ds} - (r_2 + K_2 L_m r_2) L_2 i_{qr} + \\ &(K_1 L_1 w_m - i_{qs}/ Cv_{ds} + i_{dr}) \end{aligned} \tag{6}$$

$$\begin{aligned} pi_{dr} = &-L_1 K_2 w_m i_{qs} + K_2 r_1 i_{ds} + (L_1 K_1 w_m - I_{qs}/Cv_{ds}) i_{qr} \\ &+ (r_2 + K_2 L_m r_2) L_2 i_{dr} + K_2 V_{ds} \end{aligned} \tag{7}$$

where $K_1 = L_r/(L_s L_r - L_m{}^2)$
$K_2 = L_m/(L_s L_r - L_m{}^2)$

C. Induction Motor

An induction motor is an asynchronous AC motor where power is provided to the rotating device with the useful resource of electromagnetic induction. Out of the two configurations, squirrel cage motor is extensively used in industrial and domestic applications due to its ruggedness, low maintenance cost, easy installation and superior electrical characteristics. However, in special applications where maximum starting torque is required like traction, a slip ring or wound rotor induction motor is used.

An induction motor is sometimes known as a revolving transformer due to the fact the stator (stationary element) acts as one winding of the transformer and the rotor (rotating element) is the other winding of the transformer factor.

D. Uncontrolled Bridge Rectifier

The output of SEIG is connected to a three-phase uncontrolled rectifier. The purpose of connecting a uncontrolled rectifier is to get a fixed DC from 3-phase AC. An ordinary low-cost diode rectifier will serve the purpose here. A series reactor connected at output terminals of the diode rectifier reduces the current ripple and a shunt capacitor reduces the ripple in the output voltage.

E. Multi-Level Inverters

Multilevel inverters are the ideal choice of industry to work with high voltages and is an attractive alternative in the area of high-power medium-voltage energy control. An inverter is a power electronic static device that converts constant DC voltage to alternating voltage preferably a sinusoidal voltage. The AC voltage may be at any desired voltage and frequency with the usage of appropriate transformers, switching, and manage circuits. Inverter don't have any transferring factors and are applied in a sizable sort of packages, from small switching power components in computers, to large modules that delivery bulk energy. The most common type of inverter which is used to generate AC voltage from DC Voltage is two level inverters. A two-level Inverter creates two different voltages for the load i.e. suppose we are providing V as an input to a two-level inverter then it will provide + $V/2$ and – $V/2$ on output [4]-[5].

The cascaded H-bridge multi-level inverter with 5 levels is chosen in the proposed simulation. H-bridge inverter is considered for simulation since it is extensively used in applications of distributed generation with renewable sources. Especially, for integrating solar energy and wind energy roof top installations H-bridge inverters in cascaded mode are employed.

Classification of Multilevel Inverter as shown in the "Fig. 2,".

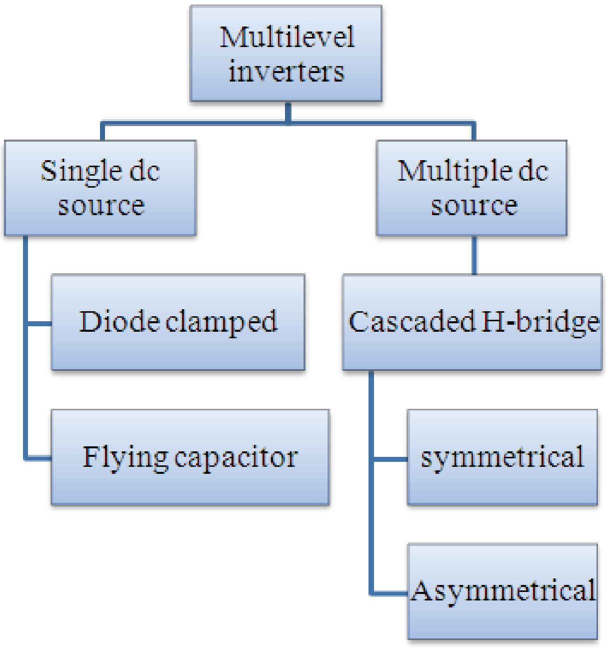


Figure 2. Classification of Multilevel Inverter

III. SIMULATION RESULTS

In this section, the wind driven Self Excited Induction Generator (SEIG) fed with five level cascaded H-Bridge inverter for wind power conversion system using Asynchronous machine as a load is simulated using MATLAB/SIMULINK [6]-[8]. By applying different loads with respect to time on asynchronous motor rotor speed and motor torque were calculated and stator current's THD analysis has been explained with the simulation results below.

"Fig. 3," shows the MATLAB/SIMULINK of proposed system comprising of a wind turbine driving an asynchronous generator. The generator output is given back to back converters with DC link in between. Here five level H-bridge cascaded inverter is used to covert fixed DC to variable AC. This AC is used to drive an induction motor which is acting as an isolated load. "Fig. 4," shows control signal generation for single cell of H bridge inverter, "Fig. 5," shows the circuit diagram of a three-phase, five-level cascaded H-bridge inverter.

The Self Excited Induction (SEIG) generated 385 volts and 3-phase output voltage wave forms shown in the figure 6, the bridge rectifier converts that AC power to DC power and the magnitude of the rectified voltage is 312 volts as shown in the "Fig. 7."

The multilevel inverter converts the rectified DC power to the AC power and the phase voltage is 370 volts as shown in the "Fig. 8.", line voltage of multilevel inverter is 358 volts waveforms this is shown in the "Fig. 9.", line current of multilevel inverter is 3.5 amperes as shown in the "Fig. 10,"

Different load torques are applied on Asynchronous machine at different intervals of time. Load torque versus time graph shown in the "Fig. 11,". Full load torque is considered as 26.72N-m

Rotor speed in RPM and motor torque in N-m of asynchronous motor for different load torques at various values of modulation index are considered for simulation. Found speed of the rotor is inversely proportional to the motor torque as shown in the "Fig. 12,". From the "Fig. 12," rotor speed decreases by the application of load torque at different intervals. Rotor speed, asynchronous machine torque at different load torques are tabulated in in the table I.

Stator currents of asynchronous machine of all three phases viz. phase A, phase B and phase C s are shown in the "Fig. 13,". The magnitude of these currents at unity slip under no load conditions is very high.

Rotor currents with respect to time on rotor of asynchronous machine of all three phases viz. phase A, phase B and phase C are shown in the "Fig. 14,". Frequency of these rotor currents is high at unity slip since rotor speed is less. As the rotor speed increases, slip of the asynchronous machine decreases and hence rotor frequency decreases.

Total Harmonic Distortion (THD) of multilevel inverter output in phase A found 8.37% as shown in the "Fig. 15,".

(i) Total Harmonic Distortion (THD) of stator current of asynchronous machine in phase A with modulation index (MI) of 1.0 at switching frequency of 1050Hz as shown in the "Fig. 16,".

(ii) Total Harmonic Distortion (THD) of stator current of asynchronous machine in phase A is shown in the "Fig. 17," The modulation index is considered as 1.0 at a switching frequency of 1550Hz.

(iii) Total Harmonic Distortion (THD) of stator current of asynchronous machine in phase A with modulation index (MI) of 1.0 at switching frequency of 2050Hz is shown in the "Fig. 18,"and

(iv) Total Harmonic Distortion (THD) of stator current of asynchronous machine in phase A with modulation index (MI) of 1.0 at switching frequency of 3050Hz is shown in the "Fig. 19,".

Total Harmonic Distortion (THD) of stator current in phase "A" for Modulation Index (MI) of 1, 0.9,0.8 and 0.7 at different switching frequencies are tabulated in tables II, III , IV and V respectively.

Phase Disposition (PD) technique with multi carrier sine waves are used to generate the gate signals for H-Bridge Inverters. Phase Opposition Disposition (POD) technique and Alternate Phase Opposition Disposition (APOD) multi carrier sine PWM techniques also can be implemented to study the behavior of asynchronous machine. Third harmonic injection pulse width modulation can also be implemented to study the behavior of the asynchronous machine for different level shifted PWM techniques discussed above.

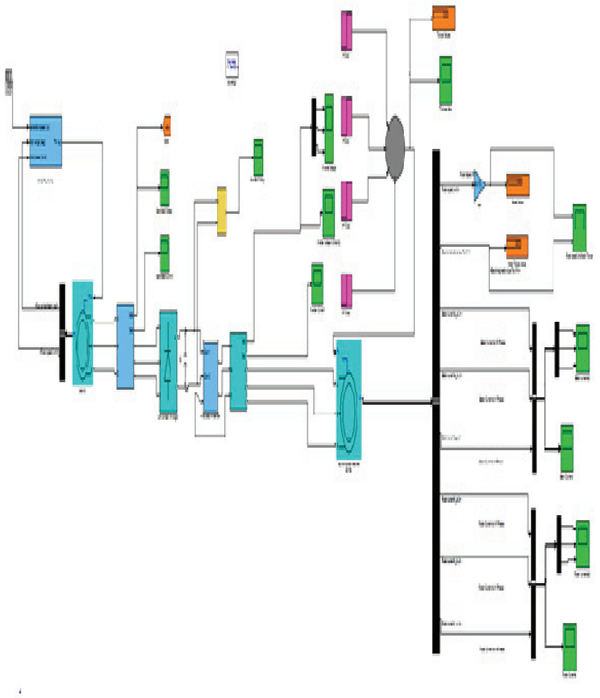


Figure 3. MATLAB/SIMLINK of proposed system.

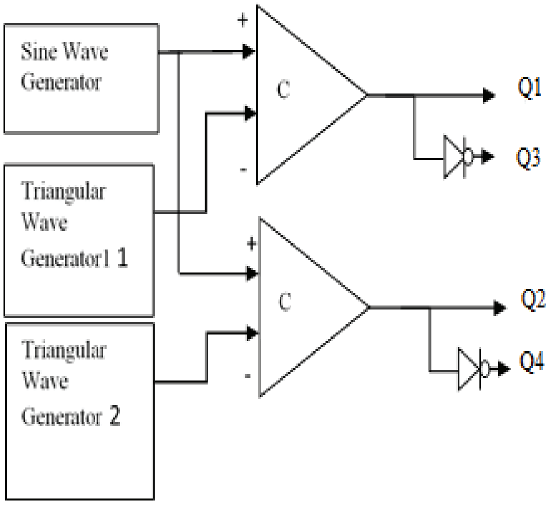


Figure 4. H-Bridge Inverter.

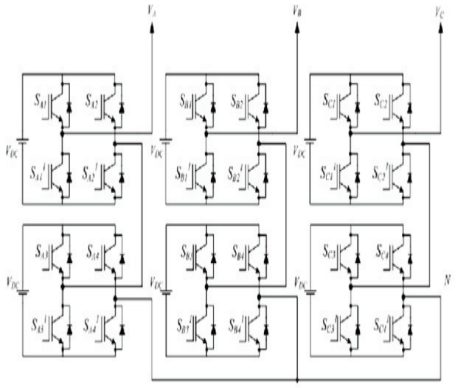


Figure 5. Three-Phase five-level cascaded H-Bridge inverter.

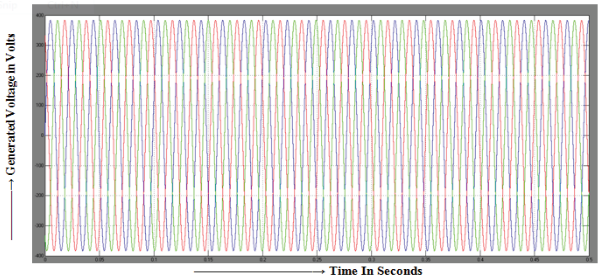


Figure 6. Self-Excited Induction (SEIG) generated voltages

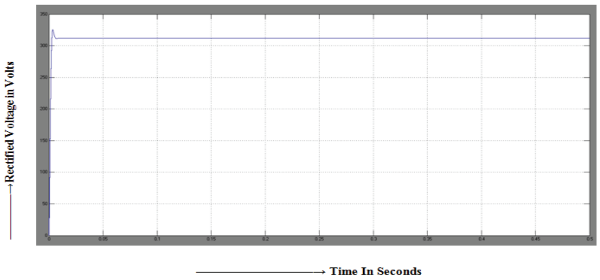


Figure 7. Rectified voltage

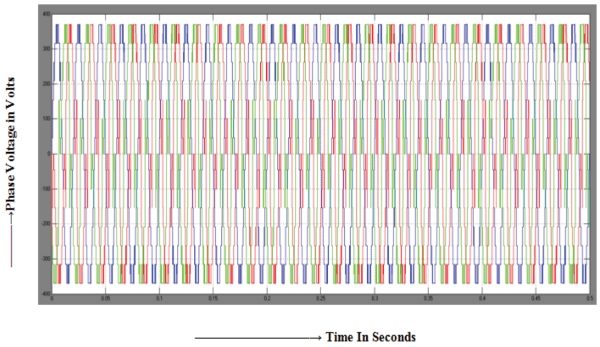


Figure 8. Multilevel Inverter output Phase voltages

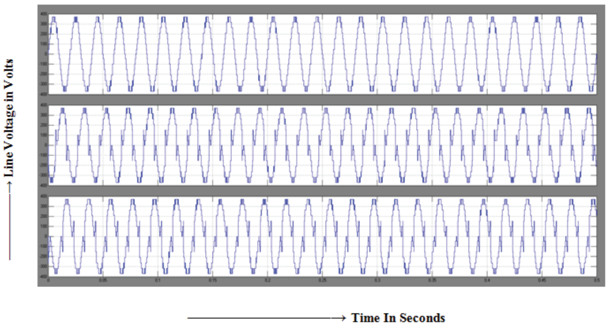


Figure 9. Multilevel Inverter output Line voltages

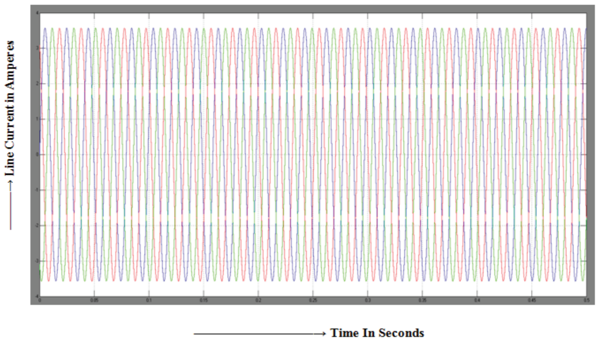


Figure 10. Multilevel Inverter output Line current

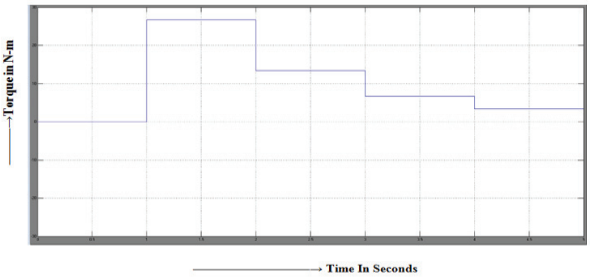


Figure 11. Applied load torque on asynchronous machine in N-m versus time in seconds.

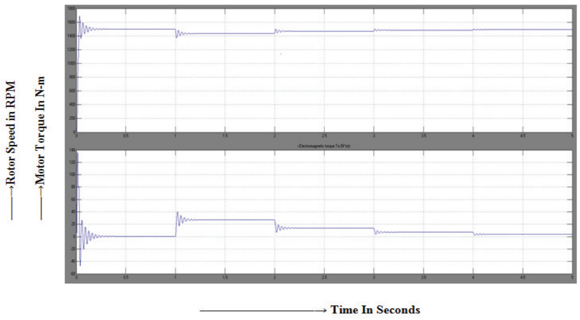


Figure 12. Rotor speed in RPM and motor torque in N-m of Asynchronous Machine

TABLE I.
SPEED, MOTOR TORQUES AT DIFFERENT LOAD TORQUES

Load Torque setting time in seconds	Load Torque	Load Torque (TL)Value in N-m	Motor Torque (Tm) Value in N-m	Rotor Speed (N) in RPM
TL at 0 second	TL at no load	0	0	1499
TL at 1 second	TL at full load	26.72	27.16	1435
TL at 2 seconds	TL at half full load	13.36	13.8	1468
TL at 3 seconds	TL at quarter full load	6.68	7.1	1484
TL at 4 seconds	TL at octa full load	3.34	3.8	1491

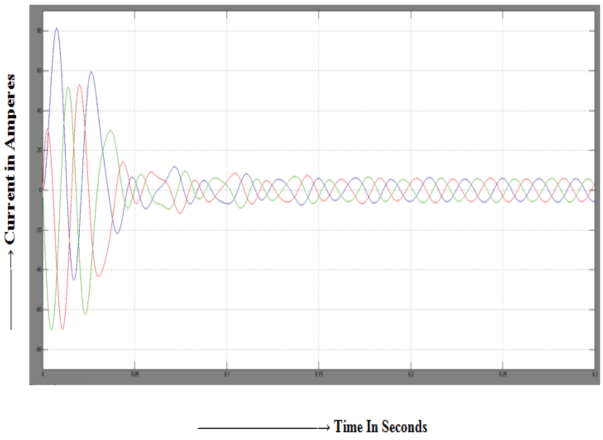


Figure 13. Stator currents of asynchronous machine w.r.t. time.

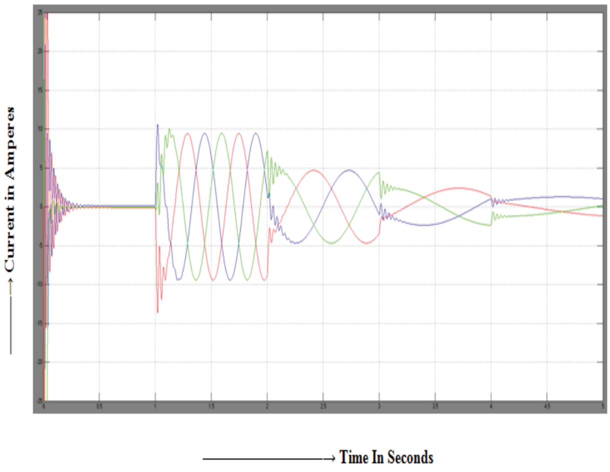
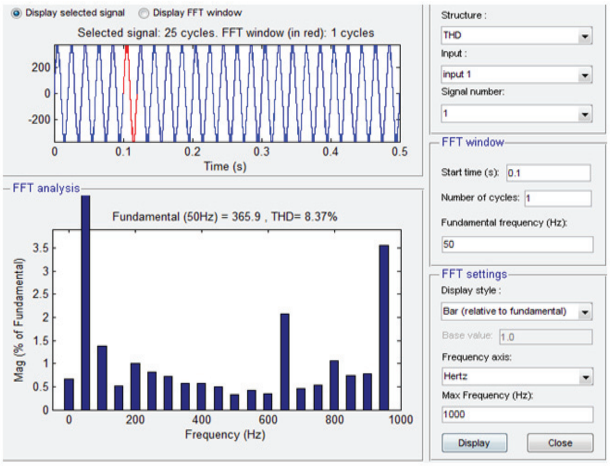


Figure 14. Rotor currents of asynchronous machine w.r.t. time.

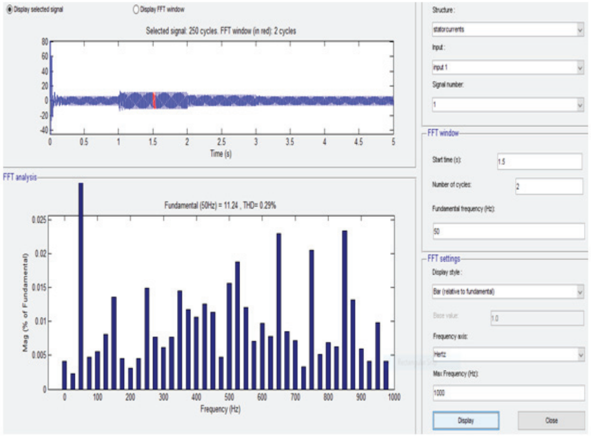


Selected signal: 25 cycles. FFT window (in red): 1 cycles

Fundamental (50Hz) = 365.9 , THD= 8.37%

Structure : THD
Input : input 1
Signal number: 1
Start time (s): 0.1
Number of cycles: 1
Fundamental frequency (Hz): 50
Display style : Bar (relative to fundamental)
Base value: 1.0
Frequency axis: Hertz
Max Frequency (Hz): 1000

Figure 15. THD analysis of multilevel inverter output.

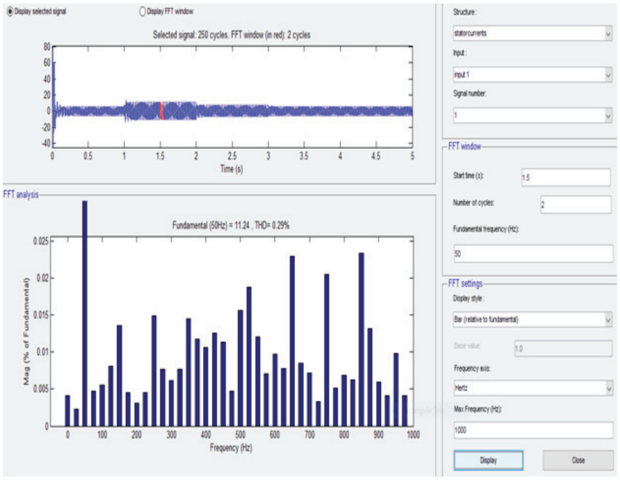


Selected signal: 250 cycles. FFT window (in red): 2 cycles

Fundamental (50Hz) = 11.24 , THD= 0.29%

Structure : statorcurrents
Input : input 1
Signal number: 1
Start time (s): 1.5
Number of cycles: 2
Fundamental frequency (Hz): 50
Display style : Bar (relative to fundamental)
Base value: 1.0
Frequency axis: Hertz
Max Frequency (Hz): 1000

Figure 16. THD analysis of stator current of asynchronous machine in phase A at Modulation Index =1

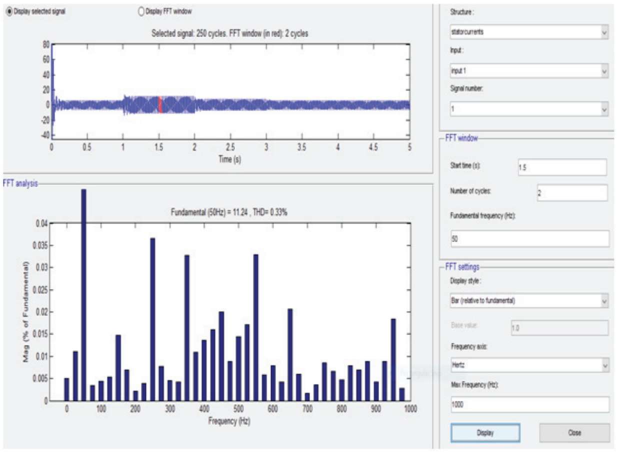


Selected signal: 250 cycles. FFT window (in red): 2 cycles

Fundamental (50Hz) = 11.24 , THD= 0.29%

Structure : statorcurrents
Input : input 1
Signal number: 1
Start time (s): 1.5
Number of cycles: 2
Fundamental frequency (Hz): 50
Display style : Bar (relative to fundamental)
Base value: 1.0
Frequency axis: Hertz
Max Frequency (Hz): 1000

Figure 17. THD analysis of stator current of asynchronous machine in phase A at Modulation Index =0.9

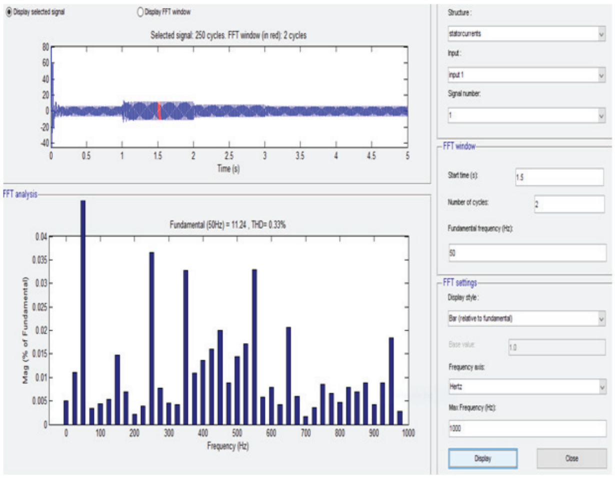


Selected signal: 250 cycles. FFT window (in red): 2 cycles

Fundamental (50Hz) = 11.24 , THD= 0.33%

Structure : statorcurrents
Input : input 1
Signal number: 1
Start time (s): 1.5
Number of cycles: 2
Fundamental frequency (Hz): 50
Display style : Bar (relative to fundamental)
Base value: 1.0
Frequency axis: Hertz
Max Frequency (Hz): 1000

Figure 18. THD analysis of stator current of asynchronous machine in phase A at Modulation Index =0.8



Selected signal: 250 cycles. FFT window (in red): 2 cycles

Fundamental (50Hz) = 11.24 , THD= 0.33%

Structure : statorcurrents
Input : input 1
Signal number: 1
Start time (s): 1.5
Number of cycles: 2
Fundamental frequency (Hz): 50
Display style : Bar (relative to fundamental)
Base value: 1.0
Frequency axis: Hertz
Max Frequency (Hz): 1000

Figure 19. THD analysis of stator current of asynchronous machine in phase A at Modulation Index =0.7

TABLE II.
THD ANALYSIS OF STATOR CURRENT IN PHASE A AT MODULATION INDEX (MI=1)

Ts	THD of Stator Current in Phase A
1050	0.29%
1550	0.29%
2050	0.33%
3050	0.33%

TABLE III.
THD ANALYSIS OF STATOR CURRENT IN PHASE A AT MODULATION INDEX (MI=0.9)

Ts	THD of Stator Current in Phase A
1050	0.34%
1550	0.32%
2050	0.32%
3050	0.34%

TABLE IV.
THD ANALYSIS OF STATOR CURRENT IN PHASE A AT MODULATION INDEX (MI=0.8)

Ts	THD of Stator Current in Phase A
1050	0.36%
1550	0.33%
2050	0.33%
3050	0.36%

TABLE V.
THD ANALYSIS OF STATOR CURRENT IN PHASE A AT MODULATION INDEX (MI=0.7)

Ts	THD of Stator Current in Phase A
1050	0.37%
1550	0.32%
2050	0.33%
3050	0.37%

IV. CONCLUSIONS

The cascaded five level H- bridge inverter fed wind driven self-excited induction generator has been simulated and waveforms of the load (Induction motor) are observed. The multi-level inverter fed drive reduces the harmonic contents in comparison with the conventional inverter fed structures. Load torque applied on asynchronous machine with respect to time at different loads, rotor speed and motor torque observed at this respective load torques applied on this asynchronous machine. Stator currents and rotor currents are obtained with respective to load torque and time interval. Total Harmonic Distortion (THD), calculated for stator current of asynchronous machine for different modulation indexes was found to be very less and the waveforms are almost sinusoidal in nature. THD was also calculated for different switching frequencies and found that that THD decrease with increased switching frequencies.

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