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IMPLEMENTATION AND CONTROL OF A CASCADED MULTILEVEL INVERTER FOR SELF EXCITED INDUCTION GENERATOR

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Abstract—This paper deals with the design, modeling and simulation for Self ExcitedInduction Generator (SEIG) with power electronics interface using MATLAB/SIMULINK. A five- level cascaded H-bridge multilevel inverter (MLI) employing a SEIG is proposed. A constant frequency multicarrier phase disposition PWM technique is implemented for the proposed MLI. DC voltage balancing is taken into account while analyzing the output waveform under the proposed modulation technique.

Index Terms*—Self Excited Induction Generator, Pulse Width Modulation, Multilevel Inverter (MLI)*

I. INTRODUCTION

This paper focuses on the simulation model and power quality analysis of SEIG – fed cascaded multilevel inverter [1]. The proposed work demonstrates the state of five – level cascaded H bridge multilevel inverter employing a SEIG. A constant frequency multicarrier phase disposition PWM technique and mathematical analysis of the cascaded H bridge multilevel inverter is developed. The analysis and simulation of a SEIG is carried out to study its performance as a stand- alone system. Finally simulation of MLI with DC sources and SEIG fed MLI are compared and the results are validated.

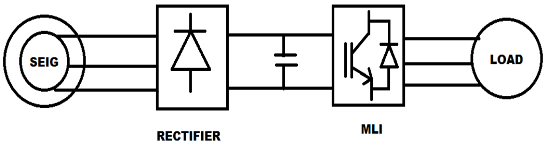

Fig. 1 Schematic representation of modeled Self Excitation Induction Generator.

II. CIRCUIT MODEL OF A THREE PHASE INDUCTION MACHINE

The dynamic model for the SEIG is similar to that of the induction motor. To model the SEIG effectively, the machine parameters should be measured accurately. 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 SEIG can be loaded with a resistive load. MATLAB/SIMULINK is used to predict the generated voltage from a given three phase induction machine rotating at a given speed with appropriate capacitors connected at the stator terminals. The equivalent circuit and phasor diagram of an induction generator are shown in figures 2 & 3 for simplicityandcore loss is neglected in this equivalent circuit [2].The terms of the equivalent circuit are defined as follows:

r_r, x_r, I_r = Rotor resistance, reactance and current expressed in terms of Stator voltage and frequency

r_s, x_s, I_s = Stator resistance, reactance and current

x_m, I_m = Magnetizing branch reactance and magnetizing current

E_t = Terminal voltage

E_a = Air-gap voltage

S = Slip

The equivalent circuit contains two variables; the slip S which is a function of speed, and the magnetizing reactance X_m which is determined by saturation and is function of the air-gap voltage E_a.[3] The magnetizing reactance can be obtained from a saturation curve for the machine but for terminal voltage variations within the narrow limits normally encountered on power systems, it is usually sufficiently accurate to consider the magnetizing reactance a constant.

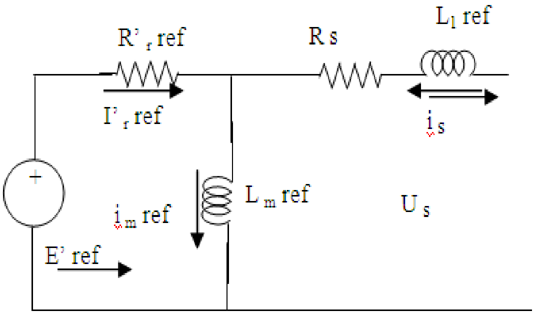

Fig 2 T – equivalent circuit of an induction machine

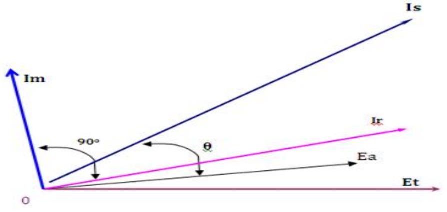

Fig 3 Phasor diagram of induction generator

The d-q axis model of an induction machine has been used to analyze the machine performance under three phase balanced conditions. If the system is studied under an unbalanced three phase operating condition, the results obtained from the d-q axis induction machine model will become very complicated. Hence, the three phase A-B-C frame of reference is preferred to describe the dynamics of the studied SEIG under unbalanced and nonlinear loading conditions [4]. The idealized circuit model of a three phase induction machine is shown in figure 4.

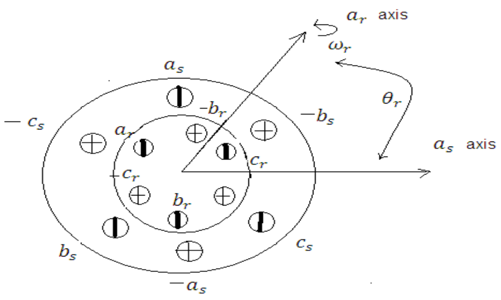

Fig 4 Idealized circuit model of a three phase induction machine.

The only one component essential for the operation of the induction generator is the magnetizing inductance L_m that produces the excitation magnetic field in the IG air gap. Its equations in their vector form are

a) Stator Voltage Equations

The stator voltage equations of the three phase induction machine is

$$V_{as} = i_{as}r_s + d\lambda_{as}\frac{d\lambda_{as}}{dt}V \quad (3.6)$$

$$V_{bs} = i_{bs}r_s + d\lambda_{bs}\frac{d\lambda_{bs}}{dt}V \quad (3.7)$$

$$V_{cs} = i_{cs}r_s + d\lambda_{cs}\frac{d\lambda_{cs}}{dt}V \quad (3.8)$$

b) Rotor Voltage Equations

The rotor voltage equations of the three phase induction machine is

$$V_{ar} = i_{ar}r_r + d\lambda_{ar}\frac{d\lambda_{ar}}{dt}V \quad (3.9)$$

$$V_{br} = i_{br}r_r + d\lambda_{br}\frac{d\lambda_{br}}{dt}V \quad (3.10)$$

$$V_{cr} = i_{cr}r_r + d\lambda_{cr}\frac{d\lambda_{cr}}{dt}V \quad (3.11)$$

a) Flux Linkage Equations

In matrix notation, the flux linkages of the stator and rotor windings from equations 3.1 to 3.6 in terms of the winding inductances and currents may be written compactly as

$$\begin{bmatrix}\lambda_s^{abc}\\ \lambda_{sr}^{abc}\end{bmatrix}=\begin{bmatrix}L_{ss}^{abc} & L_{sr}^{abc}\\ L_{rs}^{abc} & L_{rr}^{abc}\end{bmatrix}\begin{bmatrix}i_{ss}^{abc}\\ i_{ss}^{abc}\end{bmatrix}\ \text{Wb.T} \quad (3.12)$$

Where,

$$\lambda_s^{abc} = (\lambda_{as},\lambda_{bs},\lambda_{cs})^t \quad (3.13)$$

$$\lambda_r^{abc} = (\lambda_{ar},\lambda_{br},\lambda_{cr})^t \quad (3.14)$$

$$i_s^{abc} = (i_{as}, i_{bs}, i_{cs})^t \quad (3.15)$$

$$i_r^{abc} = (i_{ar}, i_{br}, i_{cr})^t \quad (3.16)$$

The superscript t denotes the transpose of the array. The sub matrices of the stator – to – stator and rotor – to – rotor windings inductances are of the form

$$L_{ss}^{abc} = \begin{bmatrix} L_{ls}+L_{ss} & -0.5L_{sm} & -0.5L_{sm}\\ -0.5L_{sm} & L_{ls}+L_{ss} & -0.5L_{sm}\\ -0.5L_{sm} & -0.5L_{sm} & L_{ls}+L_{ss}\end{bmatrix}H \quad \ldots\ldots\ldots\ldots(3.17)$$

$$L_{rr}^{abc} = \begin{bmatrix} L_{lr}+L_{rr} & -0.5L_{rm} & -0.5L_{rm}\\ -0.5L_{rm} & L_{lr}+L_{rr} & -0.5L_{rm}\\ -0.5L_{rm} & -0.5L_{rm} & L_{lr}+L_{rr}\end{bmatrix}H \quad \ldots\ldots\ldots(3.18)$$

Those of the stator – to – rotor mutual inductances are dependent on the rotor angle, that is

$$L_{ss}^{abc} = [L_{rs}^{abc}] =$$

$$L_{sr}\begin{bmatrix} \cos\theta_r & \cos\left(\theta_r+\frac{2\pi}{3}\right) & \cos\left(\theta_r-\frac{2\pi}{3}\right)\\ \cos\left(\theta_r-\frac{2\pi}{3}\right) & \cos\theta_r & \cos\left(\theta_r+\frac{2\pi}{3}\right)\\ \cos\left(\theta_r+\frac{2\pi}{3}\right) & \cos\left(\theta_r-\frac{2\pi}{3}\right) & \cos\theta_r\end{bmatrix}H \quad \ldots\ldots\ldots.(3.19)$$

Here, is the per phase stator winding leakage inductance, is the per phase rotor winding leakage inductance, is the self-inductance of the stator winding, is the self inductance of the rotor winding, is the mutual inductance between stator windings, is the rotor windings, and is the peak value of the stator – to – rotor mutual inductance. Mathematical transformation like the dq can facilitate the computation of the transient solution of the above induction machine model by transforming the differential equations with time – varying inductances to differential equations with constant inductances.

III. CASCADED H BRIDGE MULTILEVEL INVERTERS

The multilevel inverter using cascaded-inverter with Separate DC Source synthesizes a desired voltage from several independent sources of dc voltages, which may be obtained from batteries, fuel cells or solar cells [5].

By different combinations of the four switches, S_1-S_4, each inverter can generate three different voltage outputs, $+V_{dc}$, $-V_{dc}$, and zero. The ac output of each of the different level of full-bridge inverters are connected in series such that the synthesized voltage waveform is the sum of the inverter outputs [6]. In this topology, the number of output phase voltage levels is defined by $m = 2s+1$, where s is the number of dc sources.

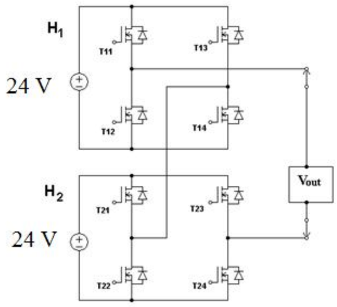

Fig 5 Single Phase Structure of a Multilevel Cascaded Inverter

VOLTAGE	T 11	T 12	T 13	T 14	T 21	T 22	T 23	T 24
-48	0	1	1	0	0	1	1	0
-24	0	1	1	0	0	0	0	0
0	1	1	1	1	0	0	0	0
24	1	0	0	1	0	0	0	0
48	1	0	0	1	1	0	0	1

Table 1. Conduction table for triggering switches

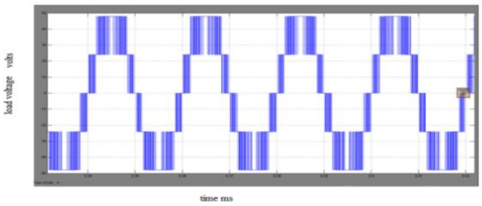

Fig. 6 Output voltage waveform of five level MLI

IV. MODULATION TECHNIQUES FOR MULTILEVEL INVERTER

Several modulation strategies have been developed for multilevel inverters. The most common used is the multi carrier sub harmonic PWM technique [7]. The principle of the multicarrier PWM is based on a comparison of a sinusoidal reference waveform with triangular carrier waveforms. m-1 carriers are required to generate m levels. The carriers are in continuous bands around the reference zero. They have the same amplitude A_c and the same frequency f_c. The sine reference waveform has a frequency f_r and A_r is the peak to peak value of the reference waveform. At each instant, the result of the comparison is 1 if the triangular carrier is greater than the reference signal and 0 otherwise. The output of the modulator is the sum of the different comparisons which represents the voltage level [8]. The strategy is therefore characterized by the two following parameters called amplitude modulation index m_a and frequency modulation index m_f:

=–;

The amplitude modulation indices are for

PDPWM=—— —;

Phase disposition PWM technique

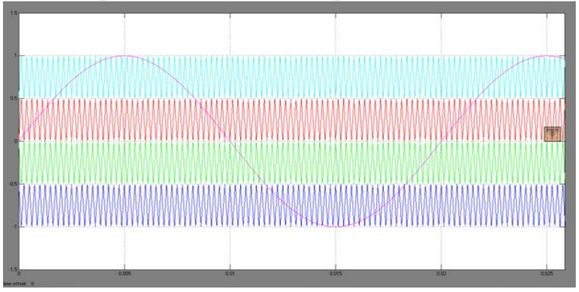

Fig. 7 Carrier arrangement for PDPWM strategy

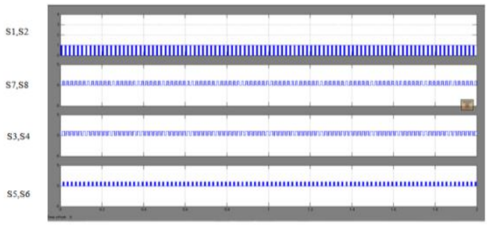

Fig. 8 Gating pattern of switches

V. SIMULATION RESULTS

A. CASCADED MULTILEVEL INVERTERS WITH SEPARATE DC SOURCES FOR STAND–ALONE SYSTEM

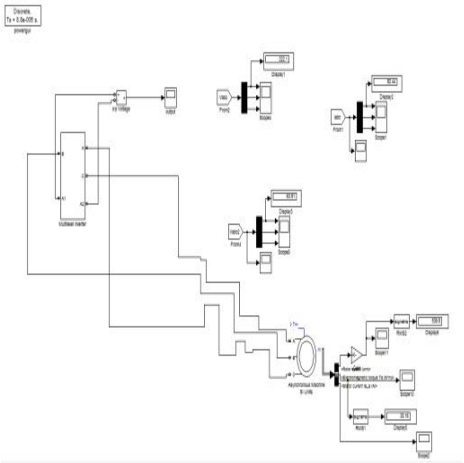

Fig. 9 Simu link model three phase MLI with motor load

It shows that it has every single phase two bridges, those are having separate DC sources, every bridge having four controllable switches and the pulses for the controllable switches. Every separate DC sources giving inputs to the bridges.

The output of the inverter is used to feed Induction Motor of rating 5HP, 460V, 50Hz. The performance of Induction Motor is shown in fig 11.fig 12 and fig 13. The Induction Motor performance parameters are a).Rotor Speed (rpm), b) Electromagnetic Torque (Nm), c) Stator current (amp)

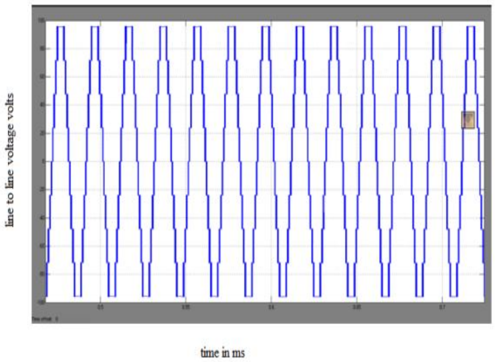

Fig. 10 Three phase cascaded MLI line to line voltage

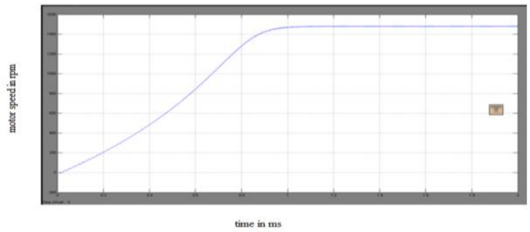

Fig. 11 Rotor Speed for induction motor

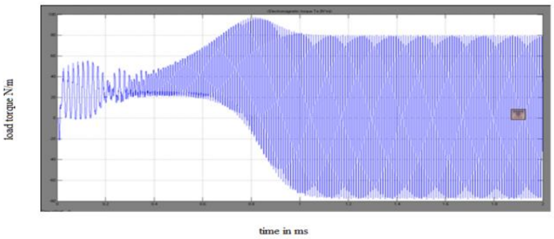

Fig. 12 Motor torque for induction motor

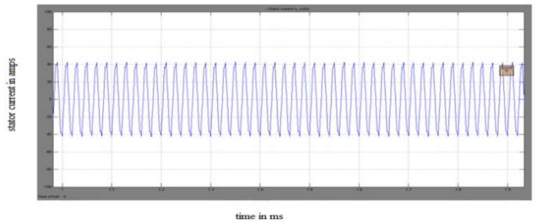

Fig. 13 Stator current for induction motor

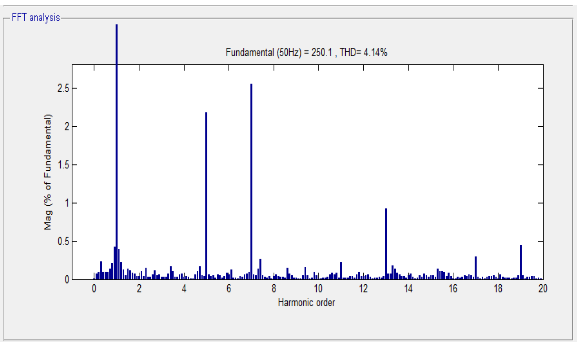

Fig. 14(a) line to line voltage THD

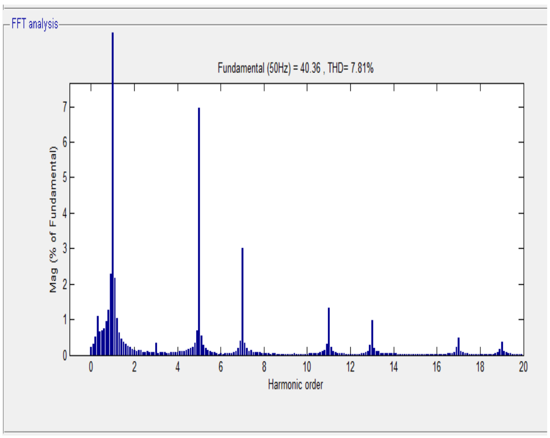

Fig. 14(b) Induction motorStator current THD

Amplitude sine	Amplitude triangle	Modulation index	Motor torque N/m	Motor speed rpm	T.H.D L to L
1	2	0.5	46.65	1485	3.94
1.2	2	0.6	51.26	1482	4.38
1.4	2	0.7	53.51	1481	4.07
1.6	2	0.8	54.82	1480	3.81
1.8	**2**	**0.9**	**55.64**	**1479**	**4.14**
2	2	1.0	56.32	1479	5.37

Table 2. Performance for induction motor in various modulation indexes

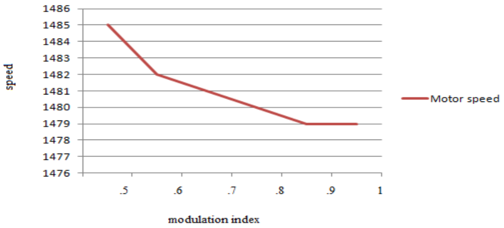

Fig. 15 Motor speed Vs modulation index

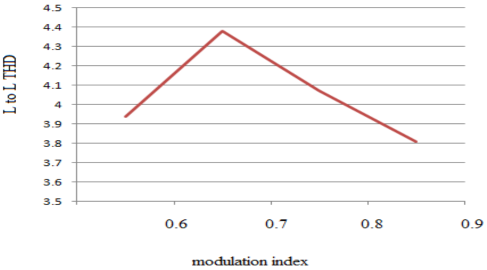

Fig. 16 line to line voltage THD Vs modulation index

B. SEIG FED CASCADED MULTILEVEL INVERTERS FOR STAND–ALONE SYSTEM

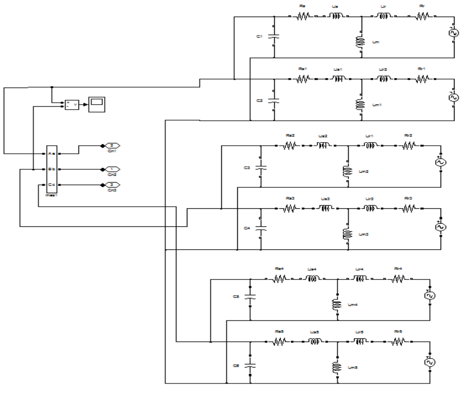

Fig. 17 Simulink model for SEIG

It shows that it has every single phase two bridges, those are having separate rectifier circuit fed to SEIG, every bridge having four controllable switches and the pulses for the controllable switches. Every separate fed SEIG giving inputs to the bridges. The three single phases MLI is connect series and then produce three phase cascaded H bridge multilevel inverter. The 5-level output voltage waveform is shown in fig 21.

The output of the inverter is used to feed Induction Motor of rating 5HP, 460V, 50Hz. The performance of Induction Motor is shown in fig 22.fig 23 and fig 24. The Induction Motor performance parameters are a).Rotor Speed (rpm), b) Electromagnetic Torque (Nm), c) Stator current (amp)

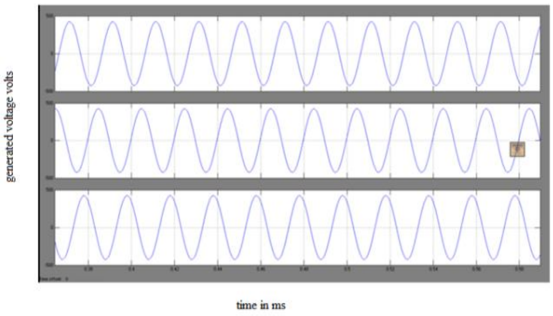

Fig. 18 Generated voltage per phase

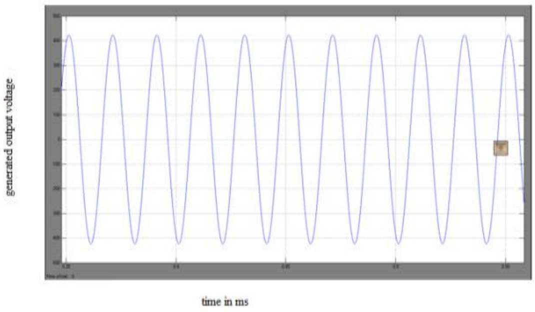

Fig. 19 Generated output voltage

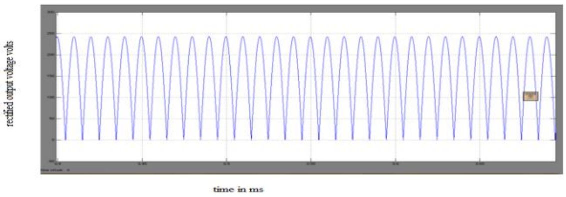

Fig. 20 Rectified output voltage

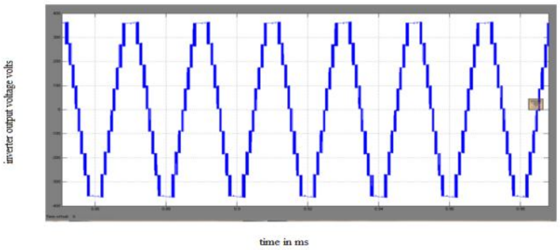

Fig. 21SEIG fedthree phase MLI line to line load voltage

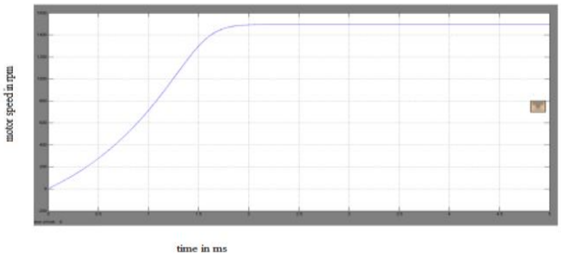

Fig. 22 Rotor Speed for induction motor

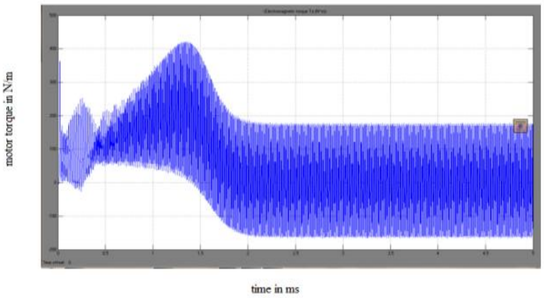

Fig. 23 Motor torque for induction motor

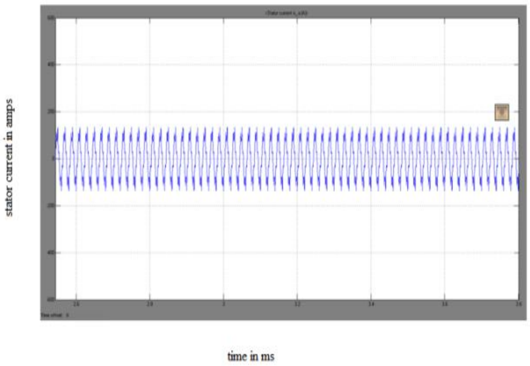

Fig. 24 **Stator current for induction motor**

Amplitude sine	Amplitude triangle	Modulation index	Motor torque N/m	Motor speed rpm	T.H.D L to L
1	2	0.5	104.8	1488	4.05
1.2	2	0.6	107.6	1488	4.45
1.4	2	0.7	108.3	1489	4.09
1.6	2	0.8	108.7	1491	3.95
1.8	**2**	**0.9**	**109**	**1491**	**4.25**
2	2	1.0	109	1492	5.46

Table 3. Performance for induction motor in various modulation indexes

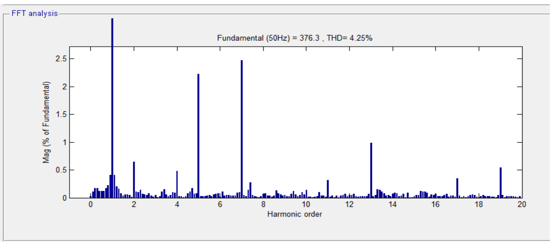

Fig. 25(a) **line to line voltage THD**

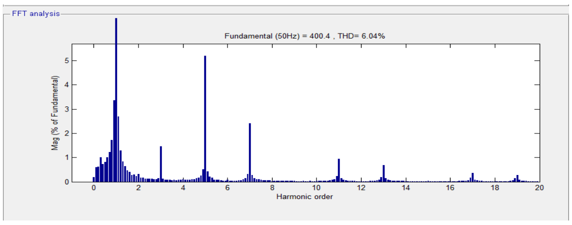

Fig. 25(b) **Induction motor stator current THD**

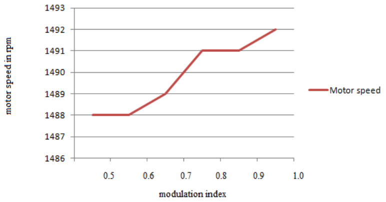

Fig. 26 **Motor speed Vs modulation index**

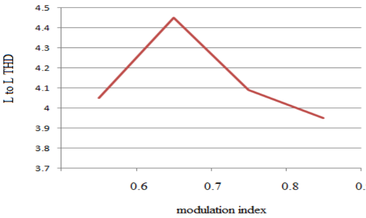

Fig. 27 **line to line voltage THD Vs modulation index**

VI. COMPARISON BETWEEN MLI WITH DC SOURCE AND SEIF FED MLI

Modulation index	THD (MLI DC)	THD (MLI WITH SEIG)
0.5	3.94	4.05
0.6	4.38	4.45
0.7	4.07	4.09
0.8	3.81	3.95
0.9	**4.14**	**4.25**
1.0	5.37	5.46

Table 4. performance of THD in various modulation index

Modulation index	MOTOR SPEED (MLI WITH DC)	MOTOR SPEED (MLI WITH SEIG)
0.5	1485	1488
0.6	1482	1488
0.7	1481	1489
0.8	1480	1491
0.9	**1479**	**1491**
1.0	1479	1492

Table 5. Performance of motor speed in various modulation index

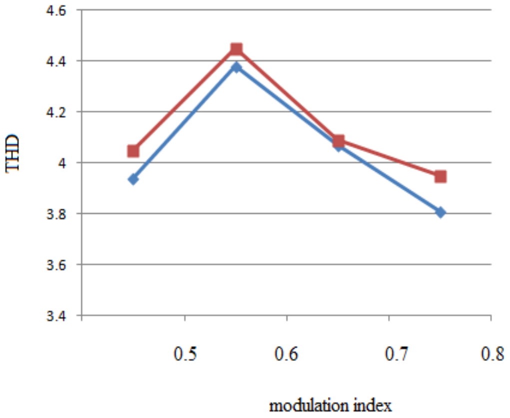

Fig. 28 **Line to Line voltage THD Vs modulation index**

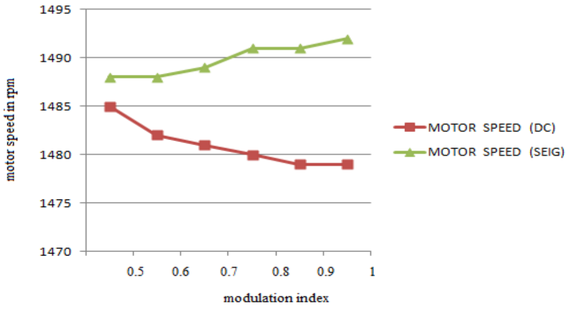

Fig. 29 Motor speed Vs modulation index

1) THREE PHASE INDUCTION MOTOR PARAMETER

Supply voltage	460V
supply frequency	50 Hz
Motor speed	1750
Motor power	5HP
Rotor type	Squirrel cage rotor type

2) SELF EXCITED INDUCTION GENERATOR PARAMETER

Supply voltage	415V
supply frequency	50 Hz
Motor speed	1500
Motor power	3.7HP
Rotor type	Squirrel cage rotor type

VII. CONCLUSION

Simulation studies and modeling of SEIG fed cascaded five –level inverter are tested with induction motor load. By employing phase disposition PWM technique, it was found that the harmonics are reduced in the stator current (MLI with DC THD- 7.81% & SEIG fed MLI THD- 6.09%), the motor torque value as improved (MLI with DC - 55.64 N/m & SEIG fed MLI -109N/m) and more effective use of MLI output voltage and hence results in improved performance of the load.

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