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E-Type Asymmetric Multilevel Inverter Based Transformer less Traction Drive

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Abstract: To overcome the limitations of conventional multilevel inverter such as of more no. of power semiconductor switches, large no. of capacitors, more switching loss etc. , a new topology of Envelope type (E-type) MLI is used. This E-type Module has some preferable features like reduced no. of components and low switching frequency. This E-type asymmetric converter uses four unequal DC sources and ten switches to generate 13 level of output voltage. SHE modulation technique is used to achieve high quality output voltage with low harmonic content. This E-type converter configuration will be used in transformer less traction drive. Nowadays Induction motors are used as electric drives for most of the electric railways. A transformer less connection is used for feeding Induction motor. This converter-inverter configuration will convert single phase AC voltage to DC and again this DC voltage will be converted into three phase AC. The output of the E-type Multi level inverter will be used to drive the Induction motors.

Index Terms: MLI, E-type, Asymmetric, SHE, Transformer less.

I. INTRODUCTION

Multilevel Inverters are considered as cost benefit devices with a wide range of applications. They have some preferable features like high quality output voltage, operation in high voltage/power, lower stress on switches etc. Multilevel converters are used in Photovoltaic systems, wind farms, HVDC, railway traction system etc. [1]-[3]. Multilevel converters constitute different arrangements of power semiconductor switches with DC links to create different voltage levels. Basically, there are three types of MLIs, such as; Diode clamped type MLI (DCMLI), flying capacitor type MLI (FCMLI), Cascaded H-bridge type MLI (CHB) etc. DCMLI was first introduced which was used in medium voltage applications. Subsequently, FCMLI and CHB MLI were introduced. The design of MLI depends upon the number of voltage levels, no. of semiconductor switches, THD amplitude, and no. of DC supplies, switch stress and total stranding voltage (TSV).

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Asymmetric MLIs are those which use unequal DC sources as their input. A 13 level asymmetric E-type MLI is presented which uses four unequal DC sources and 10 IGBT switches for its single phase operation. Selective Harmonic Elimination is used for switching modulation. Concept of Electric Drive technology was born in 19th century, and widely used in industry, agriculture, transport and daily life application in 20th century. Several existing and future designs will integrate the utilization of induction motors as the essential source for traction in electric vehicles. Structures for substantial trucks and various military fight vehicles that have huge electric drives will require impelled control electronic inverters to fulfill the incredible needs (>250 kW). Improvement of electric drive trains for these immense vehicles will achieve about expanded eco-friendliness, lower discharges, and likely better vehicle execution (acceleration and braking). Multilevel inverters are particularly appropriate for these applications as a result of the high VA rating conceivable with these inverters. Section II illustrates the proposed converter configuration and its operation. Section III illustrates SHE modulation. MATLAB Simulation and Results are shown in section IV. Section V represents conclusion.

II. PROPOSED MODULE OF E-TYPE ASYMMETRIC MULTILEVEL INVERTER

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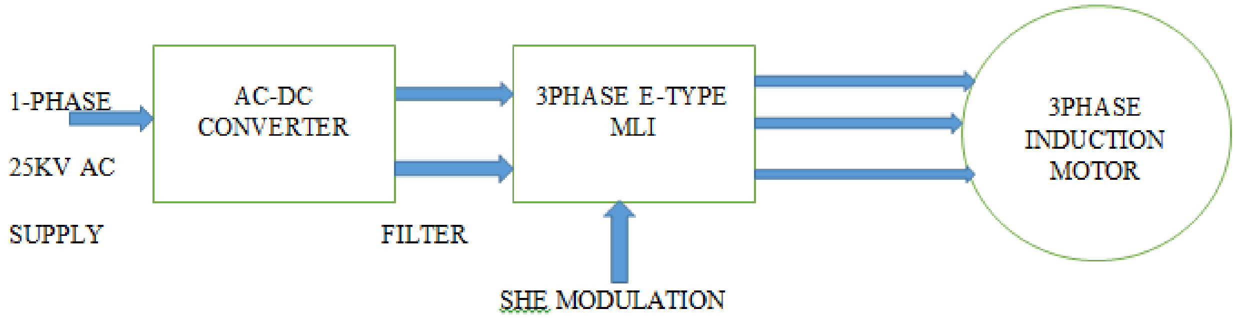

Fig. 1. Block Diagram Of E-Type Converter Based Drive System

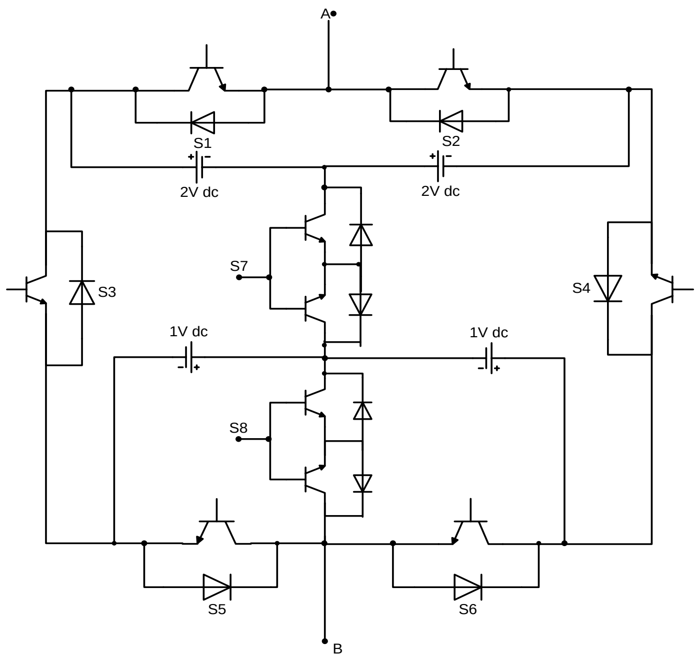

Fig. 2. E-Type Module Of MLI (Circuit Topology)

The above fig. 1 shows the basic block diagram of the proposed E-type MLI based transformer less traction drive system. In this, converter system Single phase 25KV ac voltage of the catenary is converted to DC voltage using E-type converter. This DC input is fed to the input of three phase E-type MLI. Selective harmonic elimination modulation technique is implemented to reduce the harmonics of the inverter. Then this AC output voltage of E-type converter system is used to drive the Induction motor. The basic circuit topology of E-type single phase E-type asymmetric MLI is shown in fig. 2.This module synthesizes voltage sources that produce 13 levels output, i.e. 6 positive voltage levels and 6 negative voltage levels. Two unequal DC voltages of 2Vand another two 1V sources are used as input.

There are eight power semiconductor switches such as S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8. A bidirectional switch S_7 is used to avoid short circuit of DC sources on right side or left side of the module. Another bidirectional switch S_8 is needed to achieve $\pm 5V_{dc}$. The switch pair (S_1, S_4) belong to positive voltage levels and switch pairs (S_2, S_3)belong to negative voltage levels.(S_1, S_2) and (S_3, S_4) can't be switched on at same time. The switches S_1, S_2, S_3, S_4 and S_7 are turned ON and turned OFF at low switching frequency which reduces switching loss. The switching table for 13 level yield voltages is as appeared in table 1. Using the switching table, turning on and turning off the switches accordingly, the desired voltage levels can be obtained. A comparison of conventional MLIs and the E-type MLI is as shown in below table 2.

Table- I: Switching Table

Voltage levels	S1	S2	S3	S4	S5	S6	S7	S8
+1Vdc	1	0	0	0	0	1	1	0

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+2Vdc	1	0	0	0	0	0	1	1
+3Vdc	1	0	0	0	1	0	1	0
+4Vdc	1	0	0	1	0	1	0	0
+5Vdc	1	0	0	1	0	0	0	1
+6Vdc	1	0	0	1	1	0	0	0
-1Vdc	0	1	0	0	1	0	1	0
-2Vdc	0	1	0	0	0	0	1	1
-3Vdc	0	1	0	0	0	1	1	0
-4Vdc	0	1	1	0	1	0	0	0
-5Vdc	0	1	1	0	0	0	0	1
-6Vdc	0	1	1	0	0	1	0	0
0Vdc	0	1	0	1	0	1	0	0

Table- II: Comparison of Conventional MLI with E-type MLI

	DCMLI	FCMLI	CHB	E-TYPE
No. of switches	$2(N_L-1)$	$2(N_L-1)$	$2(N_L-1)$	$5(N_L-1)/6$
No. of Diodes	(N_L+1)	$2(N_L-1)$	$2(N_L-1)$	$5(N_L-1)/6$
No. of DC links	$(N_L-1)/2$	(N_L-2)	$(N_L-1)/2$	$(N_L-1)/3$
TSV	$2(N_L-1)$	$2(N_L-1)$	$2(N_L-1)$	$10(N_L-1)/6$

Here, N_L represents no. of voltage levels and TSV represents total stranding voltage.From the comparison table, it is clear that E-type converter topology uses reduced switches and also reduced DC links as compared to other topology. The E-type rectifier produces a unidirectional output which is filtered using LC filter. This rectified output is fed to the three phase E-type inverter module. This E-type rectifier-inverter (converter) system steps down the catenary voltage to the desired voltage required by the induction motor.

III. SHE MODULATION

The pulse pattern for the E-type MLI is generated by using selective harmonic elimination pulse width modulationman. In this method, different switching angles are calculated to form a stair case wave form. This method is based on different optimization technique. In this paper, it uses Particle swarm optimization to find the switching angles of the inverter. SHE-PWM depends on the Fourier arrangement decay of the periodic PWM voltage waveform and calculation of the switching angles (α_i) so as to take out chosen low harmonic orders. It includes the solution of non-linear transcendental equation sets representing the connection among the amplitude of the fundamental wave, harmonic components and the switching angle [4]. As there are six voltage levels in a quarter wavesymmetry, therefore six switching angles are to be calculated. SHE PWM method depends on Fourier arrangement disintegration of periodic PWM voltage wave form.

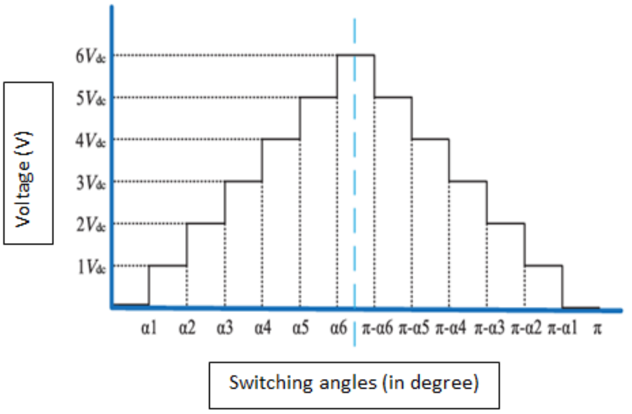

Fig 3. Wave Form Of SHE Modulation (Quarter Wave Symmetry)

Fourier series of a periodic function can be written as;

$$f_n(t) = \frac{a_0}{2} + \sum_{n=1}^{n}\left(a_n \cos\frac{2\pi nt}{T} + b_n \sin\frac{2\pi nt}{T}\right) \text{..... (3.1)}$$

As $f_n(t)$ is odd, the equation of the output can be written as

$$f_n(t) = \sum_{n=1}^{n}\left(b_n \sin\left(\frac{2\pi nt}{T}\right)\right) \text{.................... (3.2)}$$

Where $b_n = \frac{4V}{n\pi}$

$\sum_{i=1}^{n}(\cos n\alpha_i)$

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Where V= Step voltage of inverter

Now, expanding the above equation of function b_n , we will get different equations such as;

$$b_1 = \frac{4V}{1\pi}[\cos\alpha_1 + \cos\alpha_2 + \cos\alpha_3 + \cos\alpha_4 + \cos\alpha_5 + \cos\alpha_6] \quad (3.3)$$

$$b_3 = \frac{4V}{3\pi}[\cos(3\alpha_1) + \cos(3\alpha_2) + \cos(3\alpha_3) + \cos(3\alpha_4) + \cos(3\alpha_5) + \cos(3\alpha_6)] = 0 \quad (3.4)$$

$$b_5 = \frac{4V}{5\pi}[\cos(5\alpha_1) + \cos(5\alpha_2) + \cos(5\alpha_3) + \cos(5\alpha_4) + \cos(5\alpha_5) + \cos(5\alpha_6)] = 0 \quad (3.5)$$

$$b_7 = \frac{4V}{7\pi}[\cos(7\alpha_1) + \cos(7\alpha_2) + \cos(7\alpha_3) + \cos(7\alpha_4) + \cos(7\alpha_5) + \cos(7\alpha_6)] = 0 \quad (3.6)$$

$$b_{11} = \frac{4V}{11\pi}[\cos(11\alpha_1) + \cos(11\alpha_2) + \cos(11\alpha_3) + \cos(11\alpha_4) + \cos(11\alpha_5) + \cos(11\alpha_6)] = 0 \quad (3.7)$$

$$b_{13} = \frac{4V}{13\pi}[\cos(13\alpha_1) + \cos(13\alpha_2) + \cos(13\alpha_3) + \cos(13\alpha_4) + \cos(13\alpha_5) + \cos(13\alpha_6)] = 0 \quad (3.8)$$

The above equations have to be solved to achieve $\alpha_1\ to \alpha_6$ with the condition of

$0<\alpha_1 < \alpha_2 < \alpha_3 < \alpha_4 < \alpha_5 < \alpha_6 < \pi/2.$

Third harmonic multiples are eliminated in three phase system. Here, 3rd, 5th, 7th, 11th, 13th harmonic are eliminated. The switching is calculated with different modulation index

Particle Swarm Optimization:

Particle swarm optimization is one of the most prevalent nature-roused metaheuristic optimization algorithms made by James Kennedy and Russell Eberhart in 1995. In PSO, the molecule must be considered as an initial value to locate the best answer for the streamlining issue. In the basic molecule swarm optimization calculation, molecules swarm comprises of nth particles, and the situation of each molecule represents the potential solution in D-dimensional space. The molecules change its condition as indicated by the accompanying three standards:

- To keep its inertia value.
- To change the condition depends on its most optimists position and speed.
- To change the condition depends on its swarm's most optimist position and speed.

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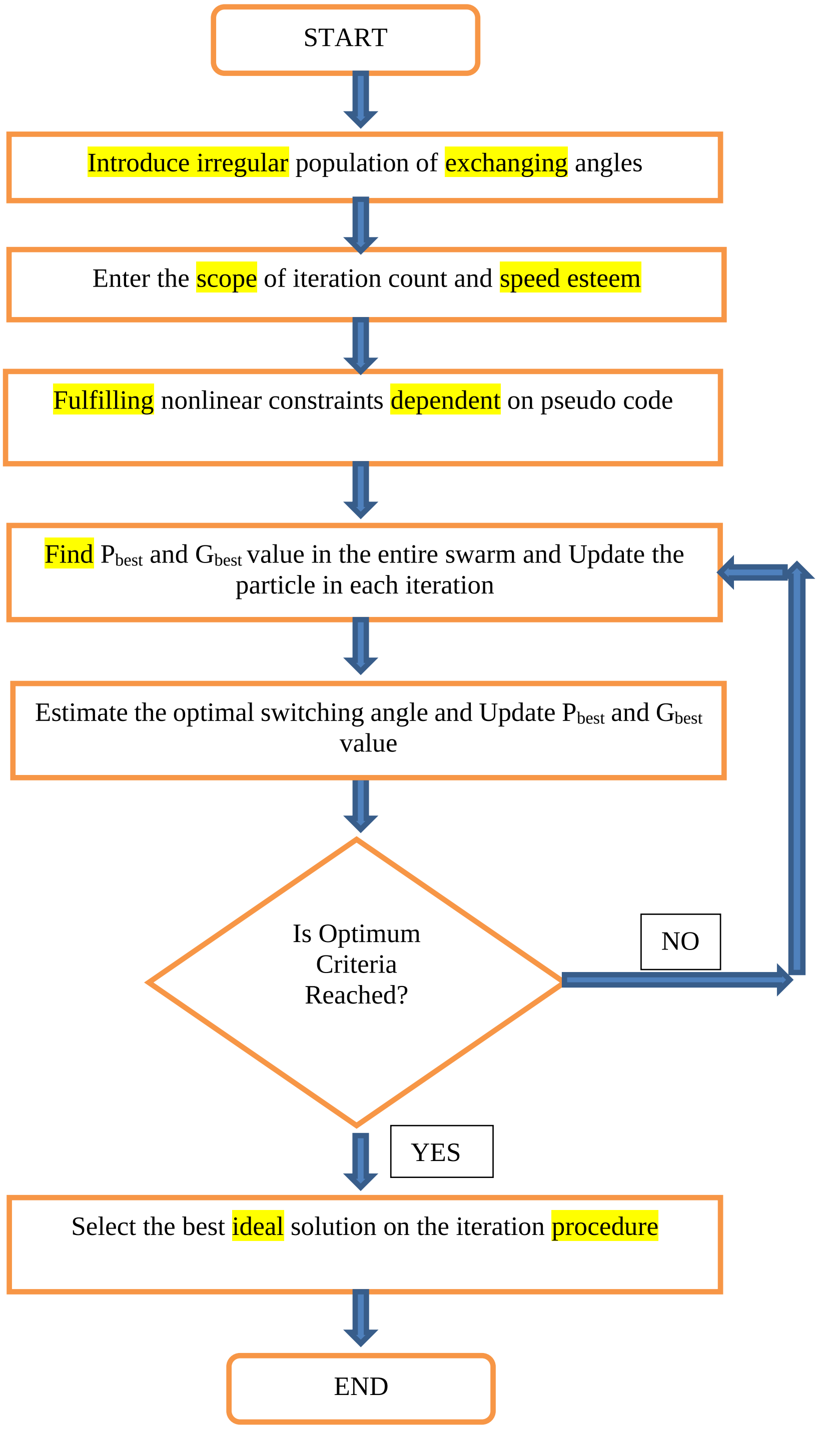

Fig. 4. Flow Chart Of PSO Algorithm

III. SIMULATION & RESULTS

The proposed converter module is simulated in MATLAB Simulink. The MATLAB Simulink model of single phase E-type MLI is shown in Fig.1.5. Here switching angles are taken as α_1=7.5°, α_2=15°, α_3=37.5°, α_4=52.5°, α_5=67.5°, α_6=82.5°.The two different input voltages of single phase E type MLI is

taken as V_1=2Volt and V_2 = 1Volt. With these two inputs, 13 level voltage were obtained. The switching angles using PSO algorithm were obtained as α_1=6.4093°, α_2=16.7684°, α_3=26.7684°, α_4=36.7684°, α_5=53.4159°, α_6=67.6139°.

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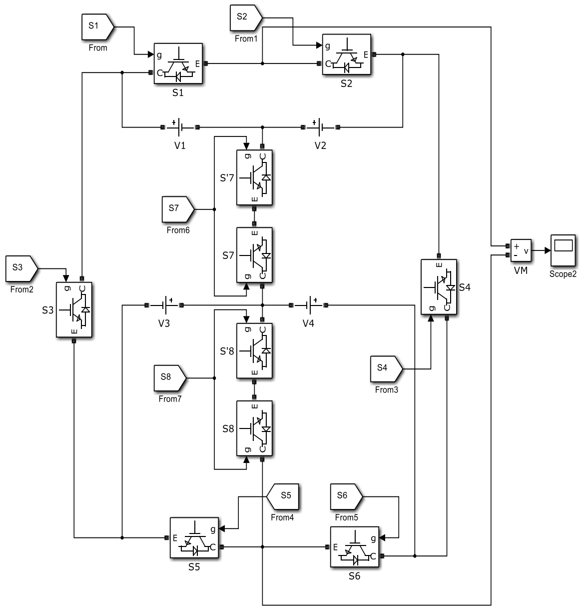

Fig. 5. Simulation Of Single Phase E-Type Inverter

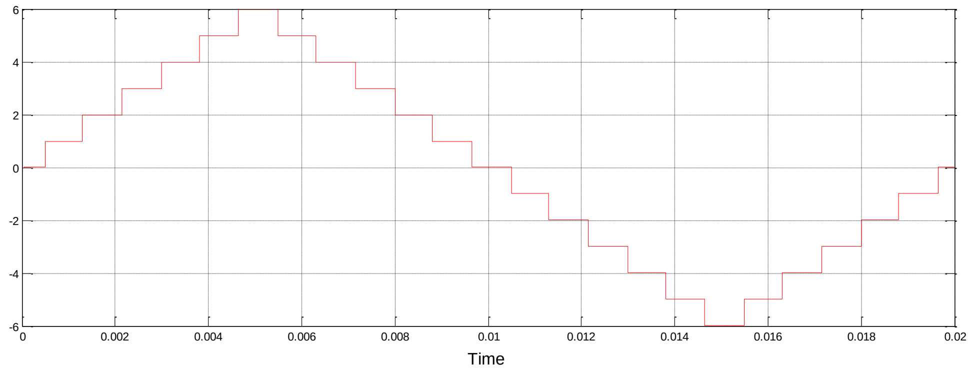

Fig. 6. Output Voltage Of E-Type Inverter Without SHE

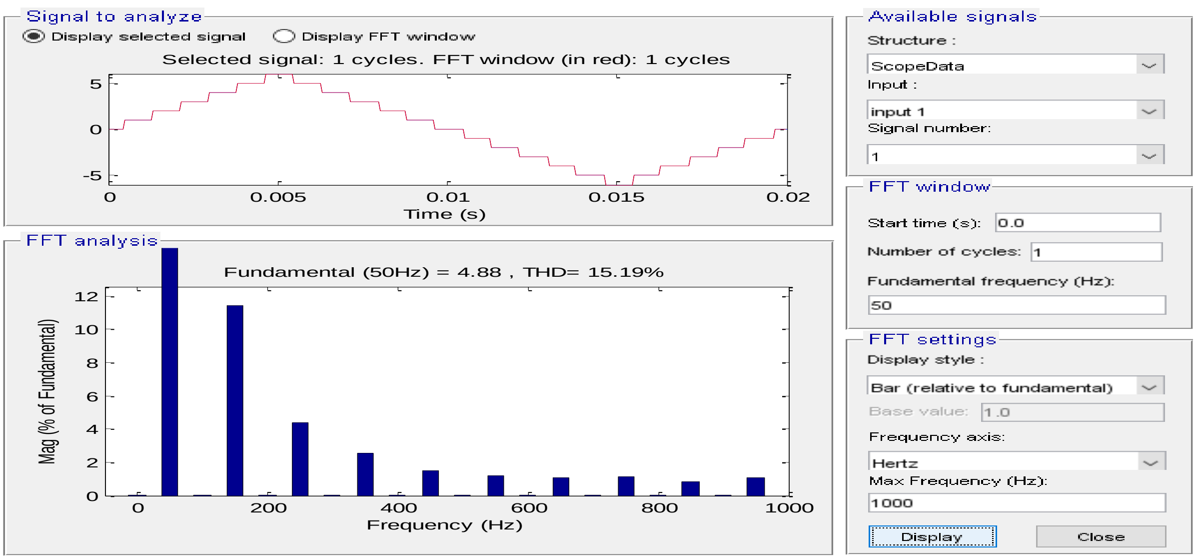

Fig. 7. FFT analysis of E-type without SHE

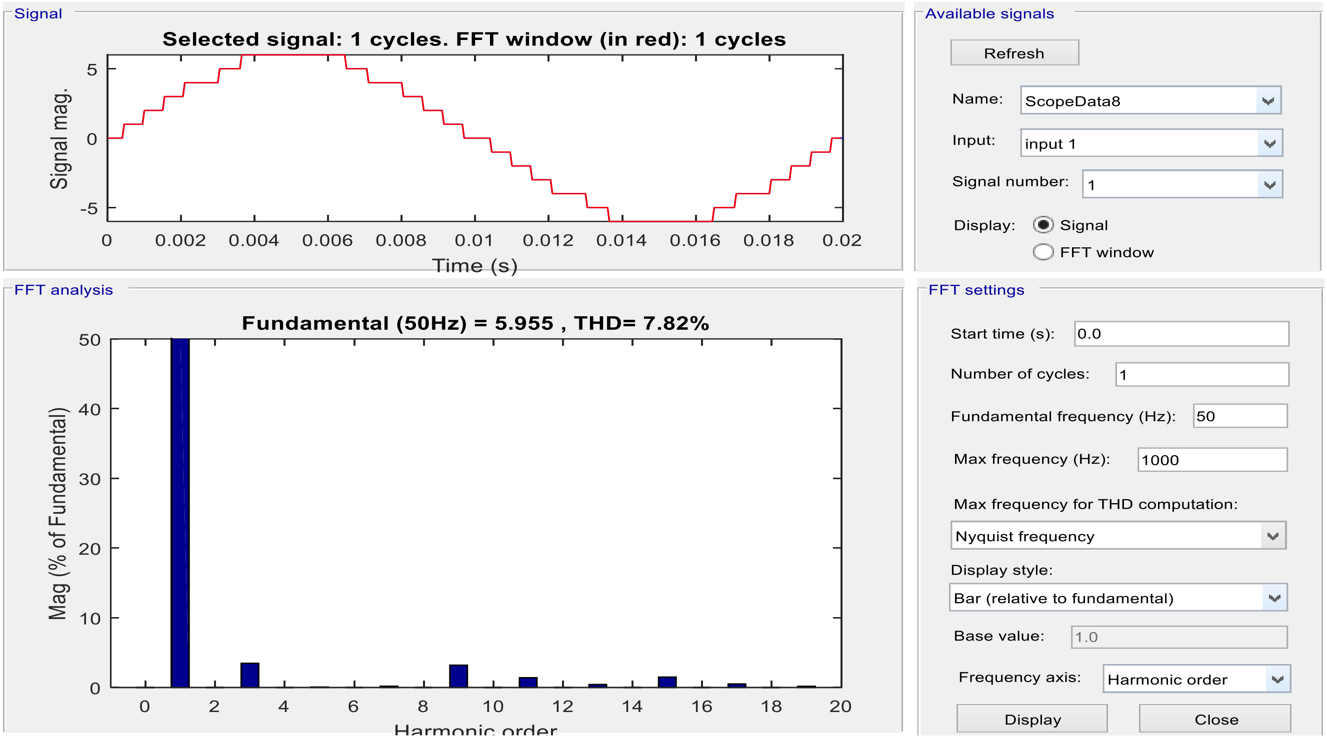

Fig. 8. FFT analysis of E-type MLI with SHE

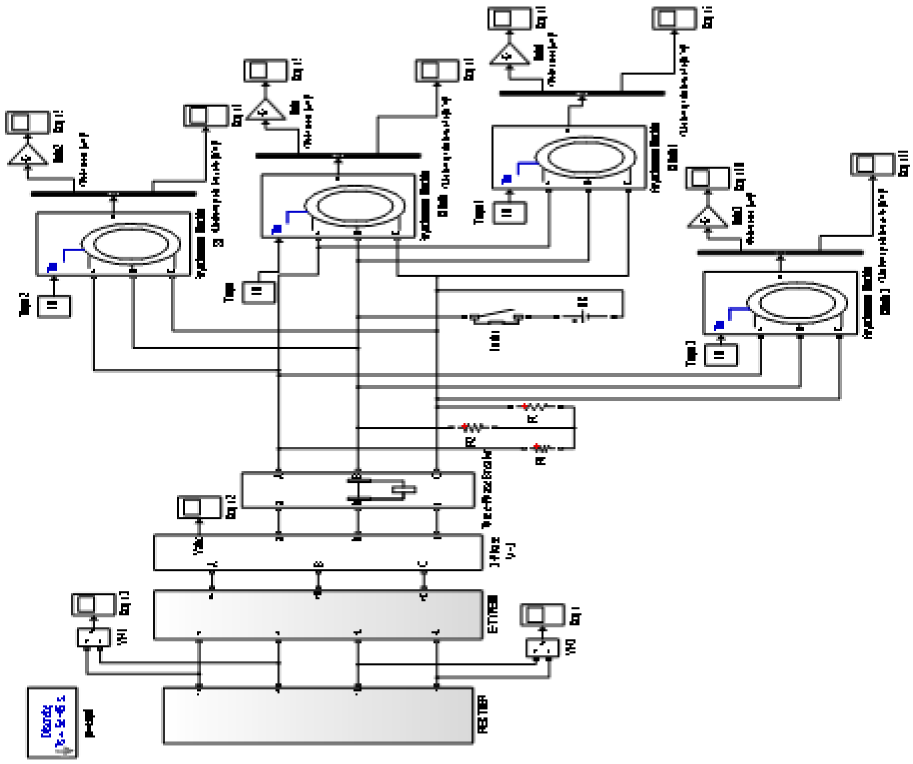

Fig. 9. Simulink Model Of E-Type Inverter Based Traction Drive

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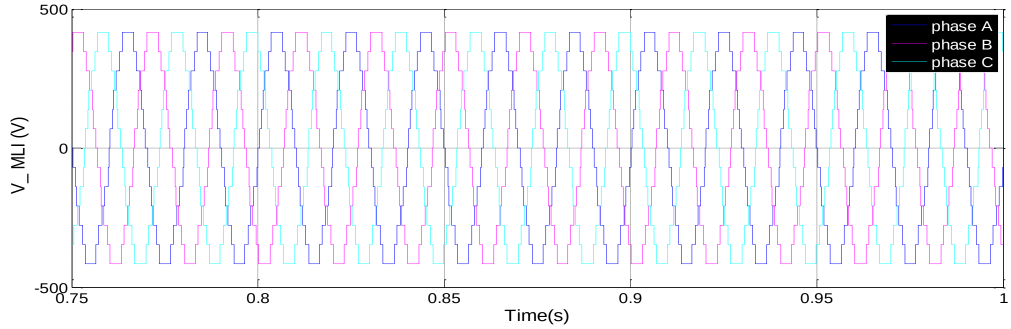

Fig. 10. Three phase output of E type MLI

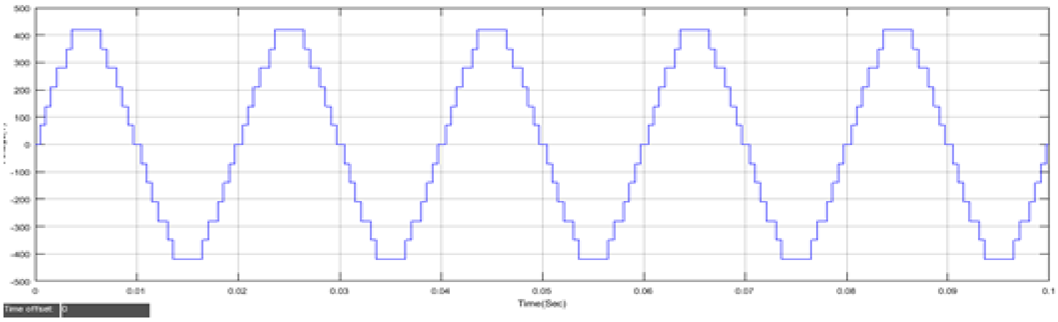

Fig. 11. Phase voltage of 3-phase MLI

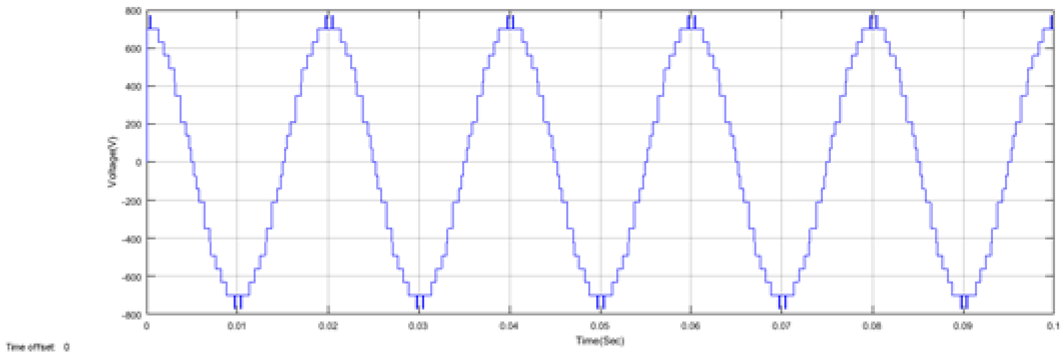

Fig. 12. Line voltage of 3phase MLI

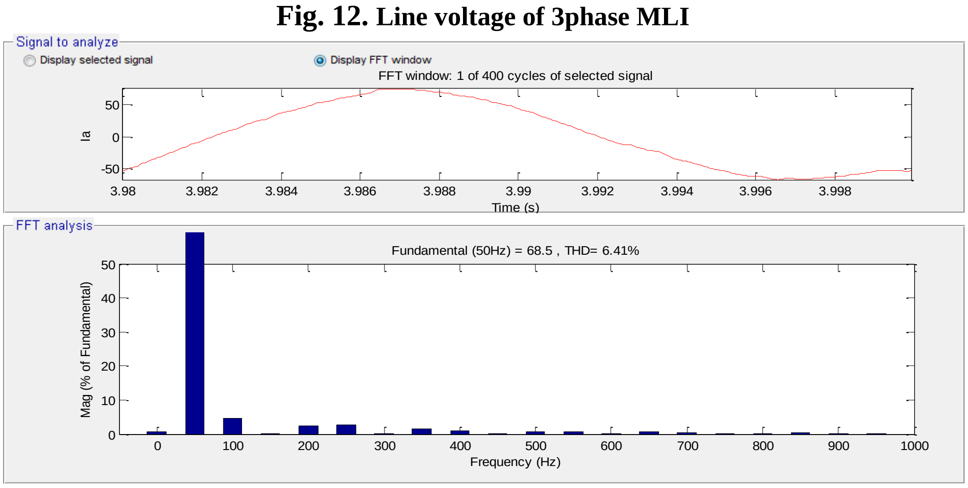

Fig. 13. FFT Analysis Of Line Current Of 3phase MLI

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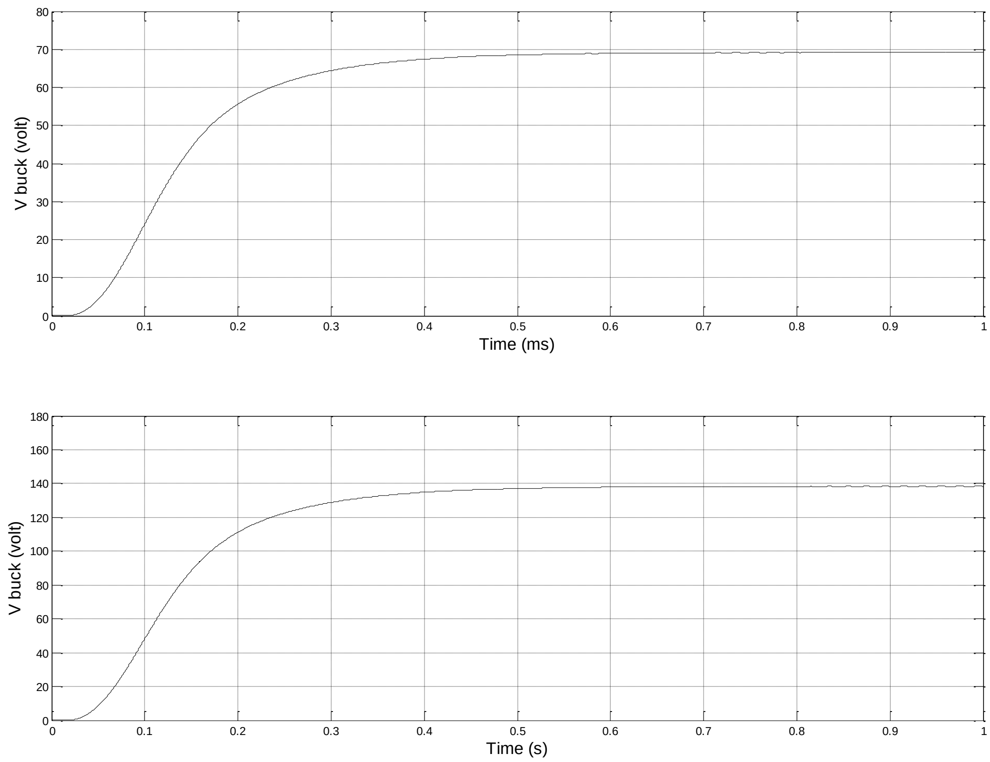

Fig. 14. Rectifier Output

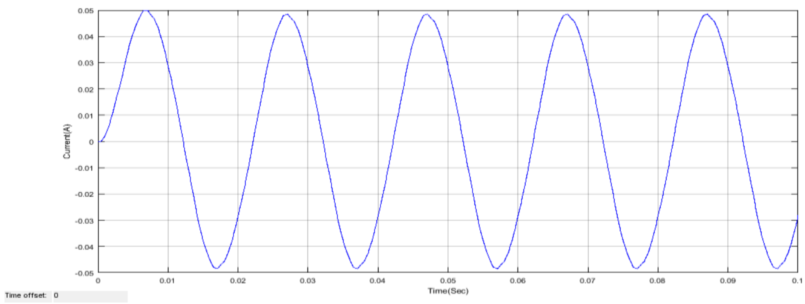

Fig. 15. Output Current Wave Form Of Three Phase E-Type MLI

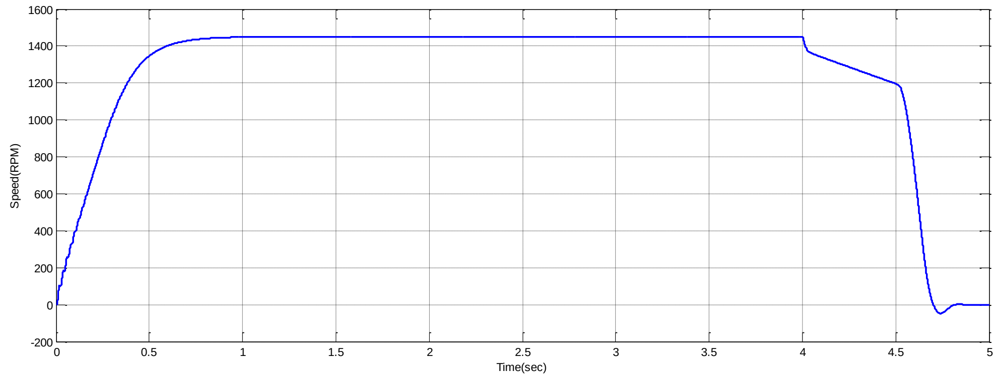

Fig. 16. Speed –Time Curve Of Traction Drive (IM)

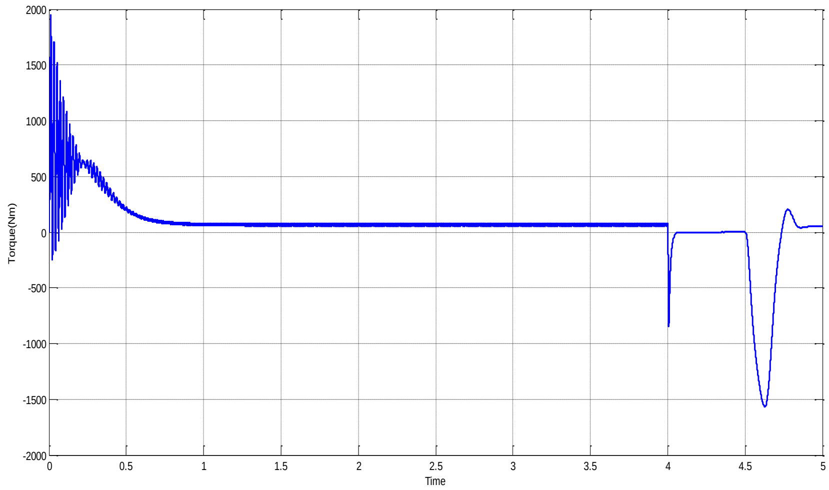

Fig. 17. Torque-Time characteristics of IM

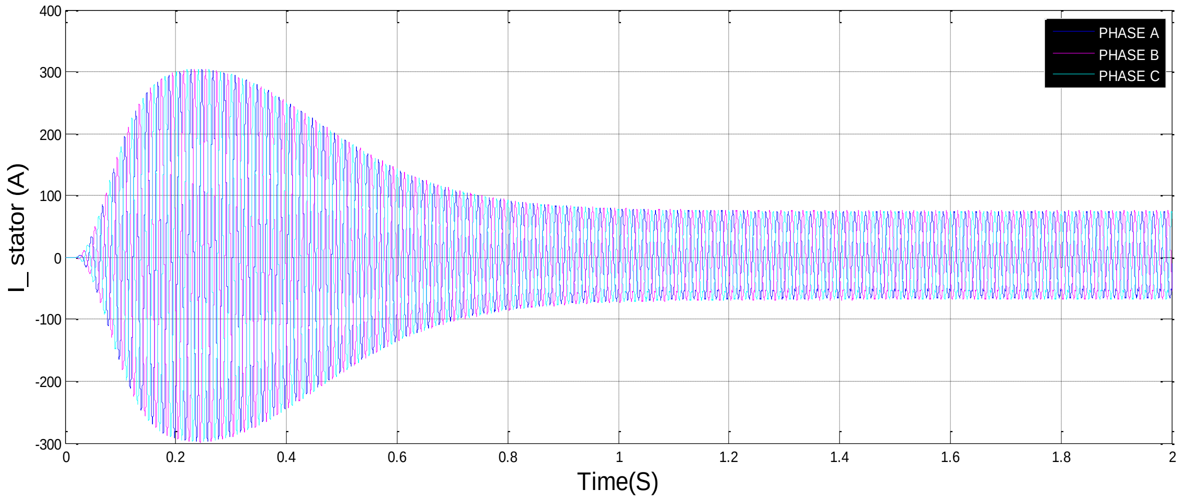

Fig. 18. Stator Current Of IM

Simulink model of single phase E-type MLI is shown in fig. 5. E-type MLI is simulated using switching angles. THD value without SHE modulation is 15.19% as shown in fig. 7 and after applying SHE THD content of voltage is lowered to 7.82% as shown in fig. 8. The Simulink model of E-type asymmetric inverter based traction drive is as shown in fig. 9. The output of three phase E-type MLI is approximately420V as shown in fig. 10. Two DC output of the rectifier is approximately 69 V and 138 V which is shown in fig. 14. The speed-time curve of the induction motor used for traction purpose is shown in fig. 16. From this curve, the motor is run for 5 seconds. The motor is accelerated from 0 to 0.5second and it is running at a constant speed till 4second. The Dc injection braking is applied at 4second and the motor is continued to run due to its own inertia till 4.5 second and it is stopped at 5 second and speed is reduced to zero.

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IV. CONCLUSION

MATLAB software was used to simulate the envelope type multilevel inverter. SHE modulation using PSO is implemented for finding switching angles of inverter. Using SHE modulation THD content of the 13 level E-type MLI is lowered from 15.19 % to 7.82 %. This E-type converter configuration can be used in traction drive. Without using transformer, the voltage of the catenary is stepped down to the voltage required by the induction motor which results in transformer less traction drive.

Parameters:

Power: 50hp
Line-line voltage:440V
Frequency:50Hz
R_s=1.405Ohm,L_s=0.005839H,R_r=1.395Ohm,L_r=0.005839H, L_m=0.1722H,Moment of inertia=0.2Kg.m^2
Modulation Index of MLI=0.7

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