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Comparison Study for SVPWM based CMV Elimination between Two- Level Inverter, Three-Level NPC Inverter and Dual Two-Level Inverter fed Induction Motor

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***Abstract*—Power Electronic AC Motor Drive Systems contain PWM inverters as one of the major parts. These PWM inverters when operated at high frequencies results in leakage current flowing through the parasitic capacitors to the ground which generates a voltage appearing between the neutral point of load and ground known as common-mode voltage (CMV). This voltage can affect the performance of the machine as it causes shaft voltage, bearing current and EMI issues. CMV elimination using conventional Three-level NPC multilevel topology has certain drawbacks. An improved SVPWM strategy using open-end winding configuration is introduced which eliminates alternating CMV and also makes CMV across machine windings zero such that no circulating common-mode current flows through it. A comparative simulation study is done between conventional and proposed configuration and verified using MATLAB.**

Keywords—Circulating current, Common-mode voltage, Open-end winding AC Drive.

I. Introduction

PWM Inverters in induction motor drives are known to cause common-mode voltage which results in leakage current flowing through the parasitic capacitors to the ground and creates drawbacks such as shaft voltage, bearing current, electromagnetic interference problems. Therefore it is extremely necessary to mitigate CMV in any AC motor drive systems [1-3]. Many studies were done to eliminate CMV which includes use of passive or active filters, Active common noise canceler and active common-mode compensator [4-5]. The most appropriate and effective way to eliminate CMV is to implement PWM techniques. Among the various PWM techniques space vector pulse width modulation (SVPWM) is proposed due to various advantages such as increased voltage utilization factor and less harmonic distortions at the output.

Conventionally used multilevel inverter in AC motor drive systems is Three-level neutral point clamped (NPC) inverter where the CMV suppression is achieved by choosing those voltage vectors which produces low level of CMV[6]. But considering various limitations like requirement of neutral point clamping diodes with neutral point voltage fluctuations and increased use of dc-link voltage, a new configuration is proposed by using two standard two-level inverters to obtain the same three level inversion as that of the conventional topology with only half the dc-link voltage.

The proposed configuration is called open-end winding induction motor fed with Dual Two-level inverter [7]. Open-end winding configuration can be easily obtained by opening the neutral point of the stator windings without any change in the structure of induction motor. Open-end winding AC drives have several advantages compared to conventional star or delta connected machines which include suppression of switching CMV, increased voltage transfer ratio, no neutral point voltage fluctuations and reduced dc-link input voltage.

An improved SVPWM is introduced such that the CMV of both inverters is equal and CMV across the machine phase windings is made zero. The circuit is implemented with a single dc-link voltage. There are chances of circulating common-mode current to flow in open-end winding induction machine with single dc-link voltage source whereas this problem is absent in case of open-end winding induction motor drives with separate dc sources. Therefore the circulating current and associated problems are eliminated in the proposed configuration since the CMV of both inverters at any instant are made same and CMV across the machine windings are always zero[8-9].

Even though the CMV across the machine phase is made zero, there are chances of alternating or switching CMV to be generated by the individual inverters which can lead to undesirable effects in AC motor drive systems. Therefore in the proposed work, the two inverters are modulated using SVPWM technique in such a manner that CMV across the machine phase is always zero and alternating or switching CMV of individual inverters is eliminated without any zero-sequence current and the associated problems are also avoided.

Simulation of Conventional Three-phase Two-Level inverter, Three-Level Neutral Point Clamped Inverter fed induction motor and proposed Dual Two-Level Inverter fed open-end winding induction motor is done in MATLAB and the results are verified. Comparison between conventional and proposed drive is done based on THD point of view for CMV Elimination.

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II. THE CONVENTIONAL TOPOLOGY

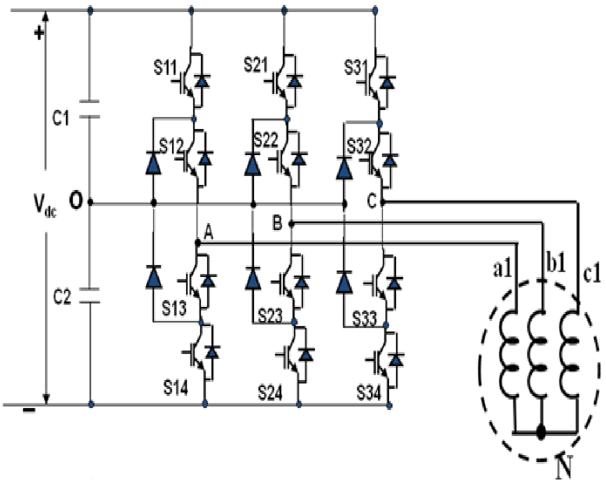

Fig.1 Three-Level NPC Inverter fed Induction motor

Among multilevel inverter topologies, Three-Level NPC Inverters have found broad applications in high power drives Fig.1 shows a Three-level NPC Inverter fed induction motor where the common-mode voltage is calculated as shown below.

$$V_{AO} = V_{AN} + V_{NO}$$

$$V_{BO} = V_{BN} + V_{NO}$$

$$V_{CO} = V_{CN} + V_{NO}$$

Adding the above equations and substituting under balanced condition ($V_{AN}+V_{BN}+V_{CN}=0$), CMV can be obtained as:

$$CMV = V_{NO} = (V_{AO}+V_{BO}+V_{CO})/3$$

The high frequency, high amplitude CMV generated by PWM inverters generate shaft voltage on the rotor side and when this induced shaft voltage exceeds the breakdown voltage of the lubricant in the bearings, it results in bearing currents. The problems associated includes erosion of bearing material, premature failure of motor bearing leading to its failure, increase in leakage current flowing through parasitic capacitors to the ground with associated EMI problems. PWM inverters which do not generate CMV are suggested as a solution to solve the above issues.

CMV suppression in three-level NPC inverter fed induction motor is done by switching those states which produce low or zero CMV [6]. Out of 27 switching states, 7 of them produce zero CMV which when utilized alone for CMV suppression can reduce the maximum level of output voltage and introduce harmonic distortions at the output. Also the power circuit requires neutral point clamping diodes with neutral point voltage fluctuations. Among various CMV mitigation methods proposed earlier PWM techniques are more efficient. SVPWM technique is implemented here which effectively utilizes the supply voltage and produce less harmonic distortions at the output. Considering the drawbacks of the conventional topology, a new three-level inverter configuration with CMV elimination is introduced which is termed as Dual inverter fed open-end winding induction motor drive.

III. OPEN-END WINDING AC DRIVE – CMV MITIGATION

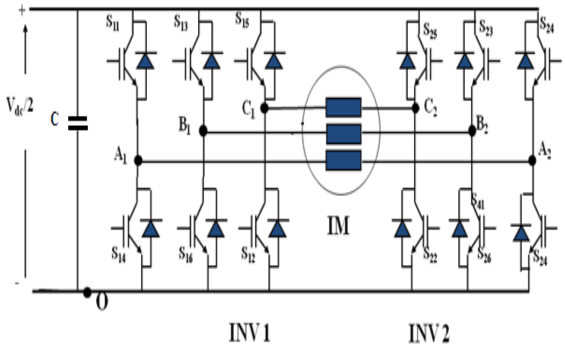

Fig.2 Dual Two-Level Inverter fed open-end winding induction motor with single DC source

Open-end winding induction machine is obtained by opening the neutral point of conventional star connected induction machine which results in six terminals instead of three and requires two standard two-level inverter on either sides of the machine as shown in Fig.2. The dc-link voltage source required is only half the value as required for the conventional three-level topology for producing the same three level inversions at the output. The CMV of individual inverters is calculated by taking the average of its pole voltages as:

$$V_{cm1} = (V_{A1O}+V_{B1O}+V_{C1O})/3$$

$$V_{cm2} = (V_{A2O}+V_{B2O}+V_{C2O})/3$$

The combined space vector diagram of Dual-inverter fed open-end configuration is similar to a three-level NPC inverter with 19 distinct voltage vectors out of the total 27 switching states. Among these 19 voltage vectors 7 of them does not contribute any CMV across the machine phase windings as shown in Fig.3.The two inverters are modulated using SVPWM strategy such that CMV of both inverters are equal and CMV across machine windings (Vcm) is zero.

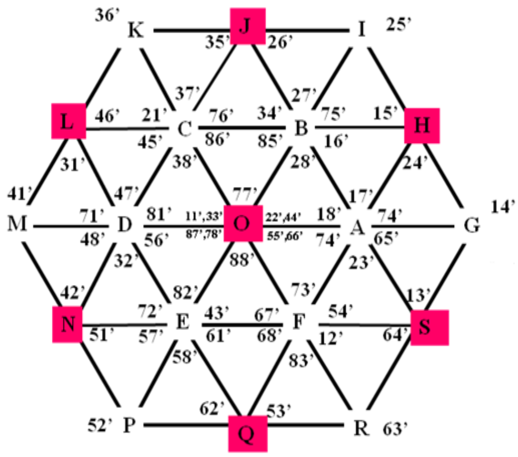

Fig.3 Combined Space vector diagram of Dual inverter with zero CMV across machine windings

Space phasor locations S, H, J, L, N, Q and O as shown in Fig.3 do not produce any CMV across the machine phase. To eliminate switching or alternating CMV of individual inverters, SVPWM for Dual inverter is modified in such a manner that inverter 1 will switch in states 1, 3 and 5 or (2, 4 and 6) and inverter 2 will switch through 1', 3' and 5' or (2', 4' and 6'. In the proposed work, space phasor locations with zero CMV across machine windings as shown in Tab.I are taken for CMV elimination.

Tab.I Voltage space vectors without alternating CMV and Zero CMV across machine windings

Space Vector Locations	**Space vector combination**	**Vcm1**	**Vcm2**	**Vcm**
S	13'	Vdc/6	Vdc/6	0
H	15'	Vdc/6	Vdc/6	0
J	35'	Vdc/6	Vdc/6	0
L	31'	Vdc/6	Vdc/6	0
N	51'	Vdc/6	Vdc/6	0
Q	53'	Vdc/6	Vdc/6	0
O	11',33',55'	Vdc/6	Vdc/6	0

From Tab.I, it can be observed that there is no alternating or switching CMV for individual inverters as the CMV for individual inverters are always same and equal to Vdc/6 and CMV across machine windings is obtained by taking the difference of CMV of individual inverters.

$V_{cm} = V_{cm1} - V_{cm2} = 0$

To achieve the proposed PWM scheme, the voltage space vectors OS, OH, OJ, OL, ON, OQ are chosen among the various voltage vectors of combined space vector diagram to obtain the space vector diagram without triplen contribution as shown in Fig.4.

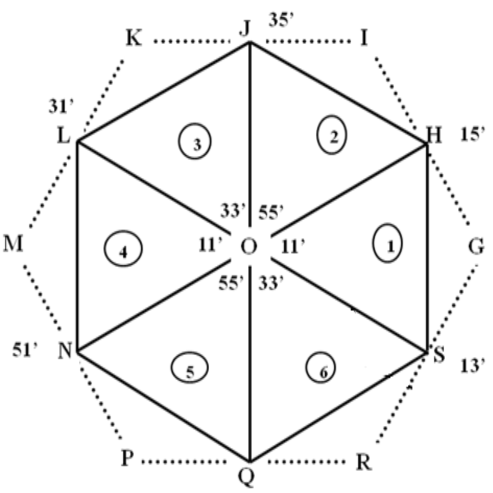

Fig.4 Space vector diagram of proposed PWM scheme

IV. SIMULATION

Simulation of Two-Level Inverter fed Induction motor, Three-Level Neutral point clamped inverter fed Induction motor and Dual Two-Level inverter fed open-end winding induction motor are done in MATLAB. A Comparative study is done between the conventional and proposed work for the analysis of CMV reduction.

A. Two-Level Inverter fed Induction Motor

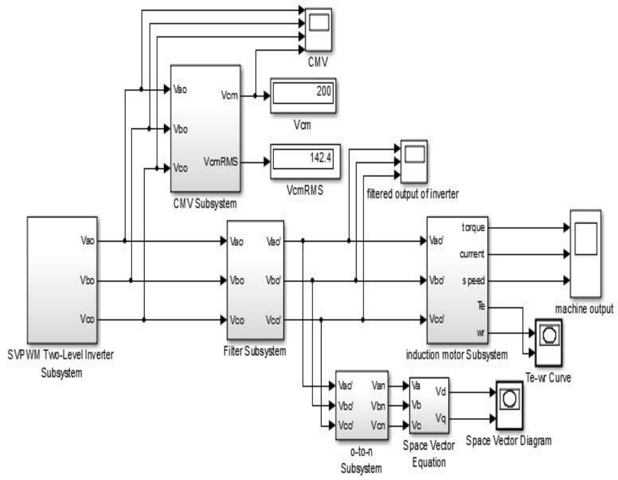

Fig.5 Two-Level SVPWM Inverter fed Induction Motor

The output of the inverter is fed to the induction motor through second order low pass filter bank as shown in Fig.5. CMV of the system is calculated by taking the average of pole voltages.

B. Three-Level NPC Inverter fed Induction motor

Implementation of space vector modulation for multilevel inverters is complex and computationally intensive due to difficulty in determining the location of reference vector, calculation of on-times and determination of switching state vectors. The proposed multilevel space vector modulation method uses the basic two-level modulation to calculate the on-times; hence computation process for n-level inverter becomes simpler and easier. Therefore a two-level inverter based SVPWM algorithm for a multilevel inverter is used for developing the model for a Three-level NPC inverter fed Induction motor [10-11].

C. Dual Two-level inverter fed open-end configuration

The conventional d-q model of a normal 3-phase induction motor is modified to compute the motor phase current of the open-end winding induction motor drive as shown in Fig.6. The inputs for this model are the PWM signals of the individual inverters and their DC link voltages. The pole voltages of the individual inverters are then computed. Subtracting the pole voltages of inverter-2 from those of inverter-1, the difference of pole voltages is obtained and supplied to the conventional d-q model of induction motor to compute motor phase currents. SVPWM is implemented using

Matlab Function block where the pulses for upper switches of the inverter are obtained [14]. Inverter is modelled using the basic output voltage equations [13]. Also it is necessary to know in which sector the reference output lies in order to determine the switching time and sequence. The angle of the reference vector can be used to determine the sector as per Tab.II. Dynamic model of induction motor is implemented in MATLAB to study the transient as well as steady state behavior of the drive system. The d-q equivalent circuit is used for obtaining the model equations in terms of flux linkage using one of the popular induction motor model known as Krause's model [12].

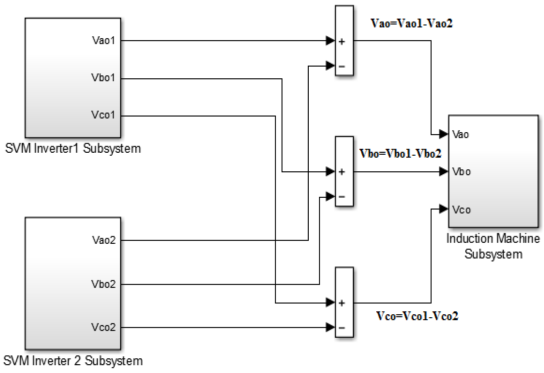

Fig.6 d-q model of an open-end winding induction motor

Tab.II Sector Identification

Sector	Degrees
1	$0 < \theta \le 60°$
2	$60° < \theta \le 120°$
3	$120° < \theta \le 180°$
4	$180° < \theta \le 240°$
5	$240° < \theta \le 300°$
6	$300° < \theta \le 360°$

V. SIMULATION RESULTS

The output voltages of Three-level NPC inverter and Dual Two-level inverter are shown in Fig.7 and Fig.8. It can be observed that open-end configuration with a dc-link voltage of 200V produce the same three-level inversion at the output similar to the conventional three-level NPC topology with a dc-link voltage of 400V. Therefore the proposed work utilizes only half the dc-link voltage compared with conventional scheme.

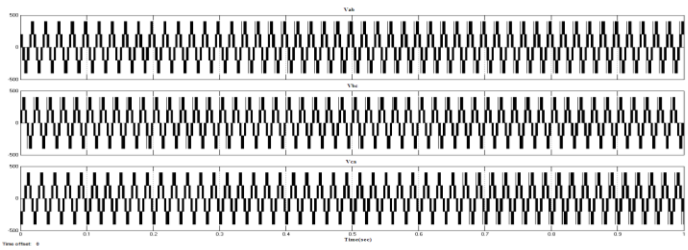

Fig.7 Three-level inverter output

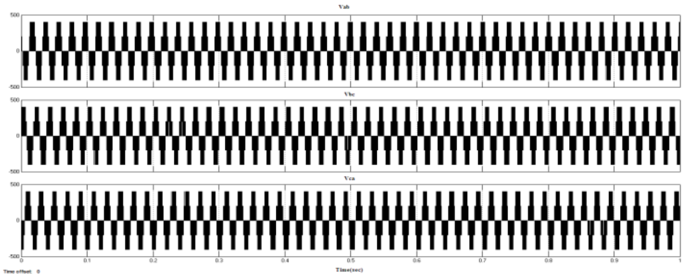

Fig.8 Dual inverter output

For three-level NPC inverter, space vector diagram obtained contains 27 switching states with 19 distinct voltage vectors as shown in Fig.9. Space vector diagram of the proposed configuration with CMV elimination is shown in Fig.10. The pole voltages and CMV of conventional and proposed topologies are shown in Fig.11, Fig.12 and Fig.13.

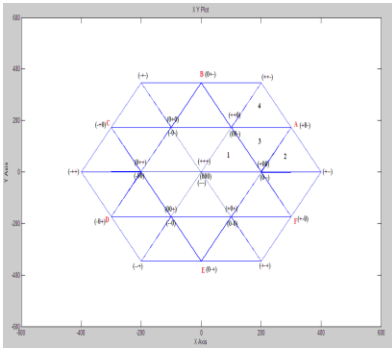

Fig.9 Space vector diagram of Three-level inverter

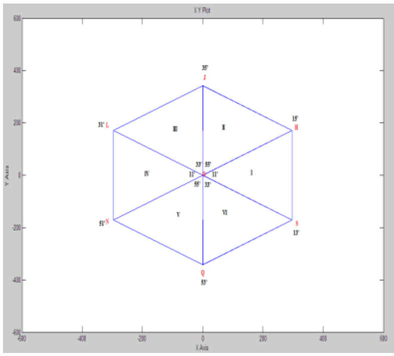

Fig.10 Space vector diagram with CMV elimination

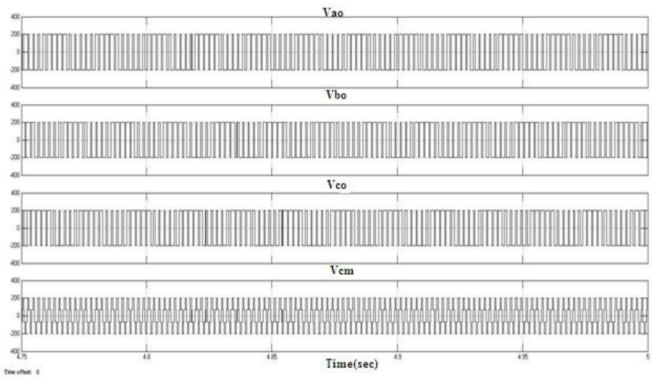

Fig.11 Pole voltages and CMV of Two-level inverter

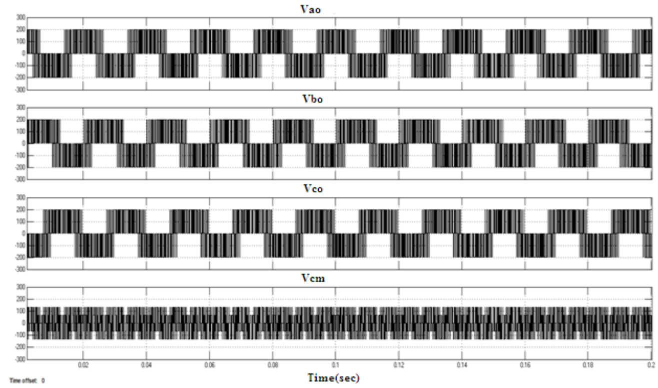

Fig.12 Pole voltages and CMV of Three-level inverter

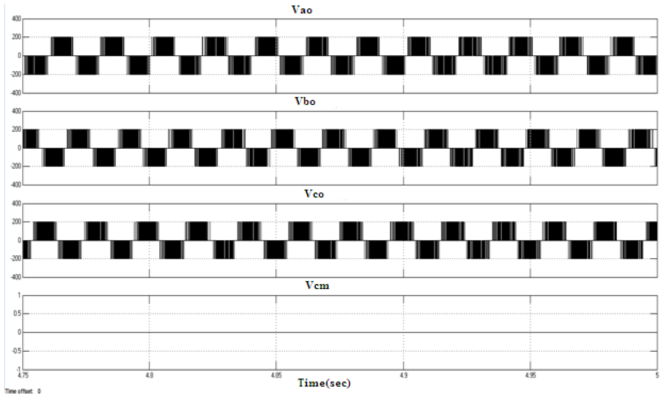

Fig.13 Pole voltages and CMV of Dual inverter

From Fig.11 and Fig.12, we can observe that peak-peak CMV for Two-Level and Three-level NPC Inverter fed induction motor is 400V and 266.6V respectively and from Fig.13 CMV of open-end induction machine configuration is 0V. Therefore CMV can be effectively eliminated using open-end induction machine configuration.

The machine parameters for a 2Hp induction machine is used for simulation as shown below:

Rr= 3.805; Rs=4.85; Lls=0.0062; Llr=0.0062; Lm=0.25; fb=50; p=4; J=0.03.

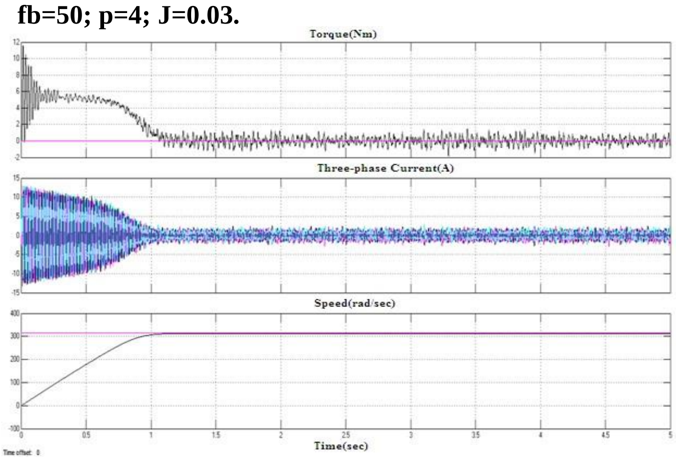

Fig.14 Machine outputs of Two-Level inverter fed induction motor

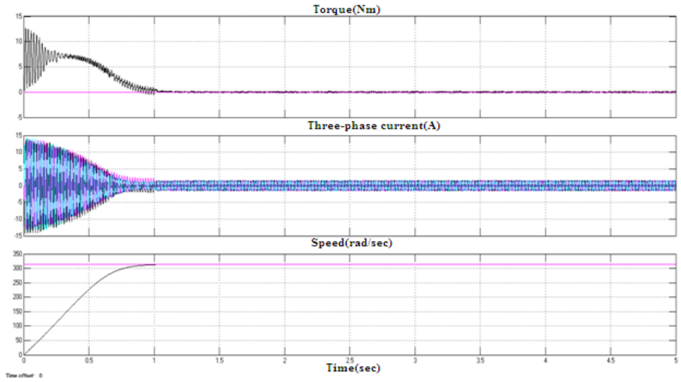

Fig.15 Machine outputs of Three-Level NPC inverter fed induction motor

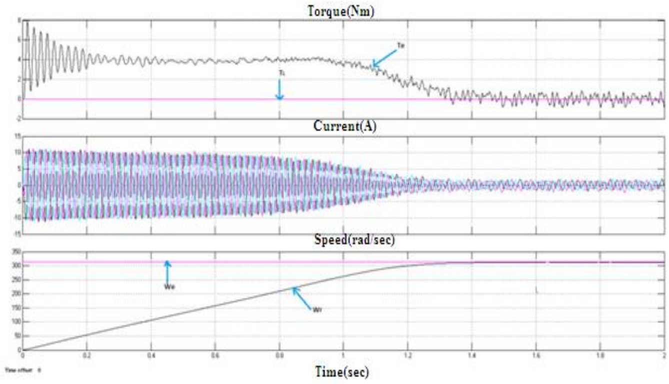

Fig.16 Machine outputs of open-end configuration at no load (T_L=0Nm)

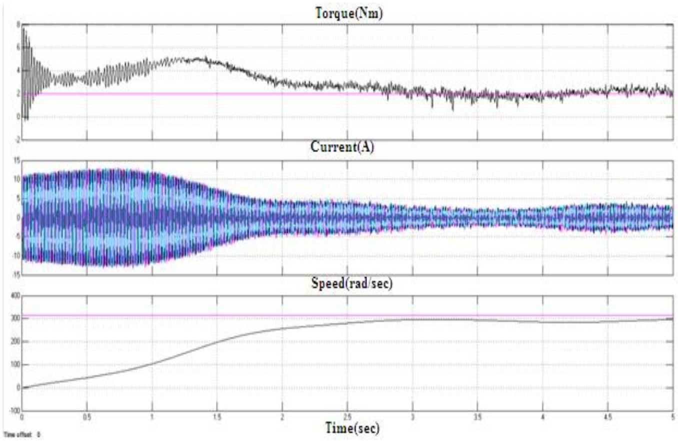

Fig.17 Machine outputs of open-end configuration under loaded condition (T_L=2Nm)

Under no load condition, initially the machine accelerates and reaches synchronous speed (ω_r=ω_e=314.2rad/sec) when electromagnetic torque reaches load torque. Under load condition with T_L=2Nm, rotor speed is reduced to ω_r=289.9rad/sec as shown in Fig.16 and Fig.17 for open-end configuration.

VI. FFT ANALYSIS

The harmonic analysis of the conventional and proposed configuration were done in FFT and compared based on THD point of view. THD of multilevel inverter is less compared to standard Two-level inverter configuration as shown in Fig.18 and Fig.19. Also in three-level NPC inverter, triplen contribution was predominant which is eliminated in the proposed Dual inverter fed open-end scheme. In the proposed scheme, the third harmonic component is 0.13% with m=0.6 from Fig.20,whereas in conventional topology, third harmonic component is 1.3%(relative to fundamental) .

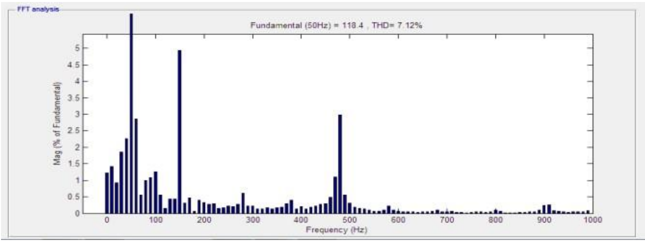

Fig.18 Harmonic spectrum of a-phase pole voltage of Two-Level Inverter

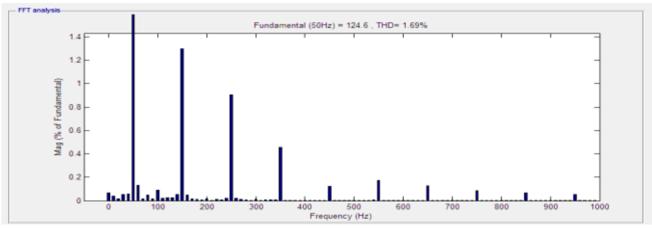

Fig.19 Harmonic spectrum of a-phase pole voltage of Three-level NPC inverter

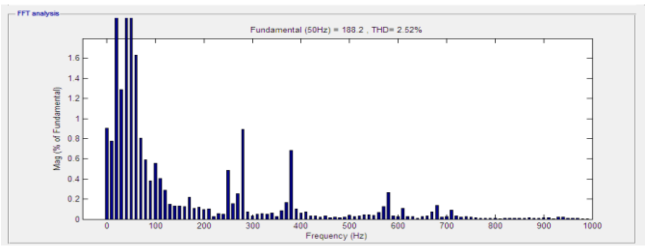

Fig.20 Harmonic spectrum of a-phase pole voltage of open-end configuration: **m=0.6**

VII. CONCLUSION

A detailed comparative study is done between Two-Level, Three-level NPC and Dual Two-level inverter fed AC Drives in MATLAB and concluded that in Dual Two-level inverter fed open-end winding induction motor drive with single dc voltage source, CMV suppression is well achieved. Also harmonic analysis between conventional and proposed scheme is done in terms of THD point of view and observed that in the proposed topology, third harmonic or triplen contribution is negligible compared with conventional Three-level NPC topology since the triplen contribution are eliminated in the present work using SVPWM and open-end winding configuration.

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