IJIREEICE

ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526

International Journal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineering

Nitte Conference on Advances in Electrical Engineering NCAEE-2016

NMAM Institute of Technology, Nitte

Vol. 4, Special Issue 2, April 2016

Simulation of Space Vector Modulation for Open End Winding Induction Motor in PSIM

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Abstract: Space vector modulation (SVM) has advantages such as wide linear range of operation, better DC link utilization, 15% more output voltage than Sine PWM and Less harmonics content. For High Voltage application switching frequency is limited by stresses on switches. Multilevel inverter provide solution for the increase operating voltage for converter above the limits of semiconductor devices along with reduced dV/dt stress. However implementation of Three-level Space Vector Modulation involves significant increase in complexity. In this paper in effort to simplify SVM for Three-level Voltage Source Inverter (VSI) ,the Three-level VSI is synthesized using a dual Two-level inverter for open-end winding induction motor drive and is simulated in PSIM. The proposed method results in reduction in the amount of switching commutations in the dual-inverter by half. The implementation of the suggested Three-level SVM scheme neither needs any look-up tables nor sector identification for the under modulation region.

Keywords: PSIM, Dual inverter, Space Vector PWM, Open end winding induction motor, modulation index.

I. INTRODUCTION

Open-end winding electric machine is also referred to as split phase machine or separately fed machine. Open-end winding electric machine is attained by taking out the neutral point of the stator winding of electric machine [1].This Open-end winding electric machines has the following advantages:

- Pole switching constraint is absent.
- On occurrence of an open or short circuit in any one of the phases, the magneto motive force (MMF) can be maintained by via the remaining two phases. This feature holds true for multi-phase machines.
- Current control for each phase of stator is possible.
- Power ratings for individual semiconductor devices is reduced by half: Power is feed from both ends of the winding of OEWIM by DC source, the devices in each phase will have to withstand half of the power compared to that of conventional neutral-connected connection.
- Voltage THD and losses in the semiconductor device is reduced [1].

Using two 2-level Three phase VSI (also known as Dual Converter) 3 phase open-end winding induction motor can be controlled See Fig. 1.In [1] PWM strategies for Open end winding Induction Motor (OEWIM) have been analyzed in comparative manner.

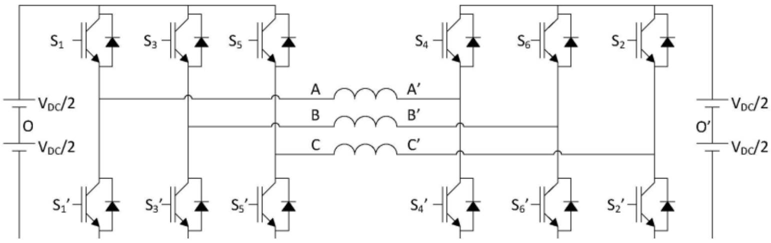

Fig. 1 Open-end Winding feed by Dual inverter

Converter operating voltage for 2 level converters is limited by the blocking voltages of the semiconductor devices and the switching frequency is limited by dV/dt stresses on the devices. Multi-level inverter (MLI) can be used in such High Voltage application [2]. Since three decades, immense research and developments have been found in multilevel inverters for high-voltage and high-power industrial drive applications. MLIs provide various advantages such as, quality voltage waveforms with low harmonic content relating to switching pattern, low dV/dt stress, reduction of common-mode voltages and lesser rating of switching devices. Besides these, it also reduces the problems associated with dielectric breakdown between motor windings influenced by dV/dt stress [2]. Although MLIs offer several advantages, the modulation and control is more complex because of the transitions between the voltage levels. Few important MLI topologies are neutral-point-clamped (NPC) [2], flying capacitor-type [3], cascaded configuration [4], hybrid

 DOI 10.17148/IJIREEICE/NCAEE.2016.01

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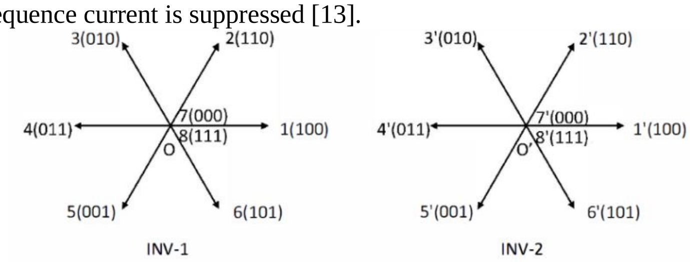
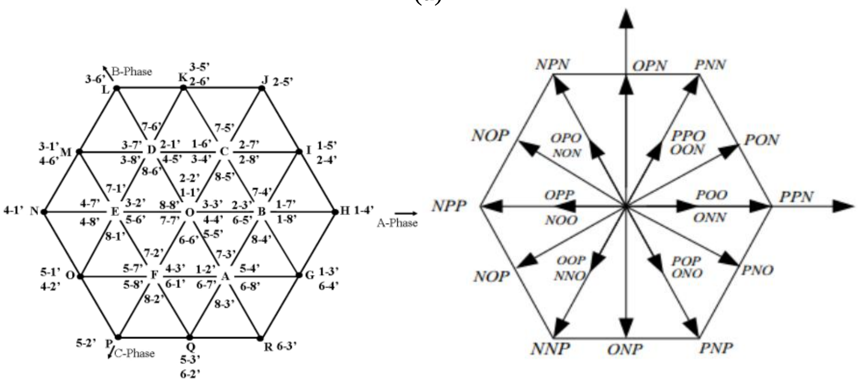
Vol. 4, Special Issue 2, April 2016

configuration [5, 6], modular MLI [7], cross-switched MLI [8] and Open-end winding induction machine (OEWIM) based configuration [9] [10].

All the above configurations of MLI undergo certain disadvantages. NPC also known as Diode Clamped inverter, the main problem involved is neutral point variation or neutral point unbalancing problem, this arise as the load current needs to carried by DC-link capacitors. Alternative scheme proposed for MLI is Capacitor clamped also known as Flying capacitor topology. Flying capacitor type MLI does not require the neutral clamping diodes as in case on NPC but needs numerous capacitors as floating DC power sources. Hybrid topologies is another alternative for synthesizing MLI but hybrid topology are more complex [11] [12]. OEWIM also undergo drawback when a single DC link is used to feed both the inverters. Zero-sequence current flows through the phase windings of the motor, resulting in stressing the semiconductor devices and the electrical drive. However, when two isolated Dc link are used for feeding the individual 2 level converters, the zero-sequence current is suppressed [13].



(a)



(b) (c)

Fig. 2 (a) Space Vector for individual 2 level inverter (b)
Fig. 3 Space Vector for 3 level SVM Space Vector of Dual inverter

The flow of this paper is as follows: In Section II Dual two level inverter feeding open end winding induction motor has been explained in brief, in Section III the proposed Space Vector PWM for Dual inverter is covered, In Section IV covers the simulation of SVM for OEWIM in PSIM, In Section V the paper concludes.

II. DUAL TWO LEVEL INVERTER FEEDING OPEN END WINDING INDUCTION MOTOR

The schematic of Three phase dual converter for an Open-end Winding Induction Motor(OEWIM) is shown in Fig. 1.where V_{AO},V_{BO},V_{CO} are pole voltages for inverter-1 while $V_{A'O}$,$V_{B'O}$,$V_{C'O}$ are pole voltages for inverter-2 . Fig. 2 (a) shows Space vector of individual inverter. Each inverter has possible 2^3 switching states. On combination of the two inverter, the total number of switching states are $2^3*2^3 = 64$ situated at 19 vector location.

Fig. 3 shows space vector for A Three level Neutral Point Clamped and it has 27 possible combinations, the number of redundant combination in case of OEWIM fed by Dual converter are more. Fig. 2(b) shows the Space Vector for OEWIM by Dual Three phase VSI.

The switching state for inverter-1 is defined as 1, 2, 3..8 and the switching state of inverter-2 is defined as 1’, 2’, 3’…8’.Now each switching state for both the inverters is defined by 3 bit binary no. as shown in Fig. 2(a), where 0 corresponds to pole voltage of $-V_{dc}/2$ (i.e. lower half switch is ON) and 1 corresponds to pole voltage of $+V_{dc}/2$ (i.e upper half switch is ON). For Ex. If the switching state of the Dual inverter is 1-7’, Switching state for inverter-1 is 1 [100], hence switches S_1, S3’, S5’ are ON from Fig. 1 while for inverter-2 switching state is 7’[000] hence S2’,S6’,S4’ from Fig. 1 are ON.

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The 3 level space vector diagram of SVM can be viewed in terms of seven sub hexagons of 2 level space vector, one inner sub hexagon and six outer sub hexagons. The inner sub hexagon has the following vertices A,B,C,D,E and F with center as O. The outer six sub hexagon have center as A,B,C,D,E and F. The entire dq plane can be split into six Sectors A,B,C,D,E,F just like in the case of 2 level space vector PWM see Fig. 4(a), further these each Sectors can be split into four Subsectors (1,2,3,4),see Fig. 4(b).So the 3 level SVM has been split into 6 sectors and 6*4 Subsectors.

III. PRINCIPLE OF THE PROPOSED SCHEME

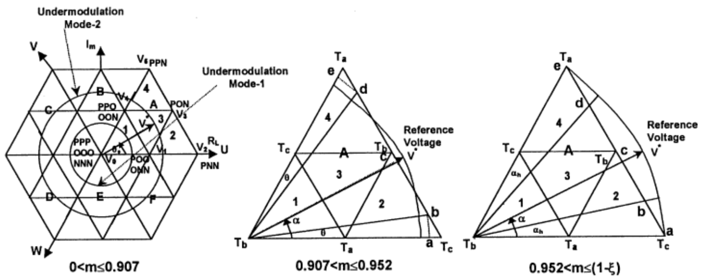
The modulation index of inverter varies from 0 to 1 and can be given in terms of the ratio of absolute value of voltage reference and peak value of 180^{O} conduction mode. Using Eq no (1) mod, the modulation index for inverter can be defined as:

$$\text{mod} = \frac{|V^*|}{V_p} \qquad (1)$$

Where V_p is peak value of 180^{o} conduction mode while $|V^*|$ is the reference voltage magnitude. SVM has been classified into four regions based on mod: (1) under modulation mode I (mod $< \pi/4\sqrt{3}$) (2) undermodulation mode II ($\pi/4\sqrt{3} <$ mod $< \pi/2\sqrt{3}$) (3) over modulation mode I ($\pi/4\sqrt{3}$ < mod < 0.952) (4) over modulation mode II (0.952 < mod < 1 – £).Fig. 4 shows the operation for all the above modes.

A. Under modulation mode I (mod < (π)⁄(4√3))

In under modulation mode I, voltage ref. V^* is confined within the inner hexagon ABCDEF with center as O, so only one inverter is sufficient to implement the required reference value. Thus switching state of inverter-2 is kept 8' (111).Though the output obtained in this case is not same as in case Neutral Point Clamped inverter ,We have preferred this method because of the less number of switching per entire cycle. Fig. 6 shows the pole voltages for both the inverter and the difference between them i.e phase voltages.



(a) (b) (c)

Fig. 4 Operation of SVM in (a)mode I and II of under modulation (b) mode I of over modulation (c) mode II of over modulation

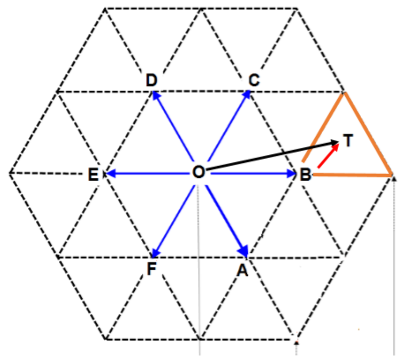


Fig. 5 Voltage ref. OT divided into two components OB and BT

B. Undermodulation mode II ((π)⁄(4√3)<mod<(π)⁄(2√3))

In this region the ref. Voltage vector lies in the middle of the inner hexagon boundary and the outer hexagon boundary. Consider the scenario in Fig. 5 the voltage reference is denoted by vector OT. Any reference vector exceeding the inner hexagon can be split into two components. One of them form the vertices of inner hexagon realized by inverter-2 while the remaining vector to be realized by inverter-1 can be given by:

$$V_{d1} = V_d^* - V_{d2}$$
$$V_{q1} = V_q^* - V_{q2} \qquad (2)$$

Where V_d^*, V_q^* are the coordinates of reference voltage V^* in dq plane and V_{d1},V_{q1},V_{d2} and V_{q2} are dq coordinate for inverter-1 and inverter-2 respectively. Consider the case shown in Fig. 5, The reference voltage OT is split into OB and

DOI 10.17148/IJIREEICE/NCAEE.2016.01

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BT.OB is realized by inverter-2 using switching state 4' [011], See Fig. 7. Knowing the value for V_{d2} and V_{q2} the coordinates for V_{d1} and V_{q1} is found using Eq. no (2). BT is realized using 2 level Space Vector PWM and output pole voltages for inverter-1 are shown in Fig. 7. Details on implementation of SVPWM for two level inverter is covered in [14].The output obtained in this mode is same as that of NPC inverter.

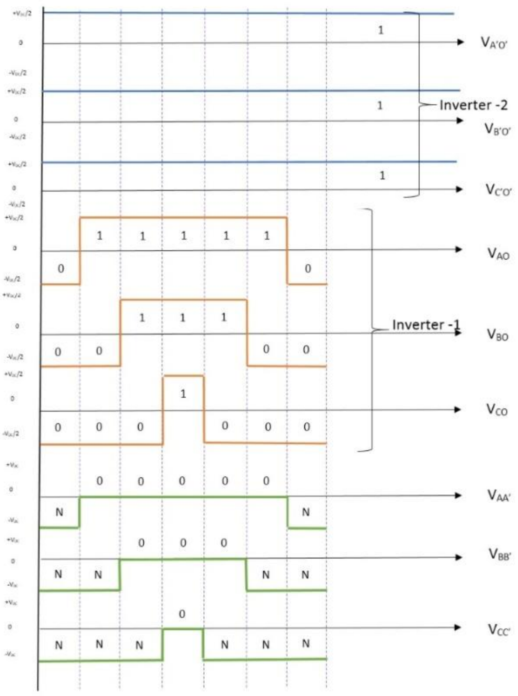

Fig. 6 Inverter-2 pole voltages, Inverter-1 pole voltages and phase voltages for undermodulation mode I (sector A, sub-sector 1)

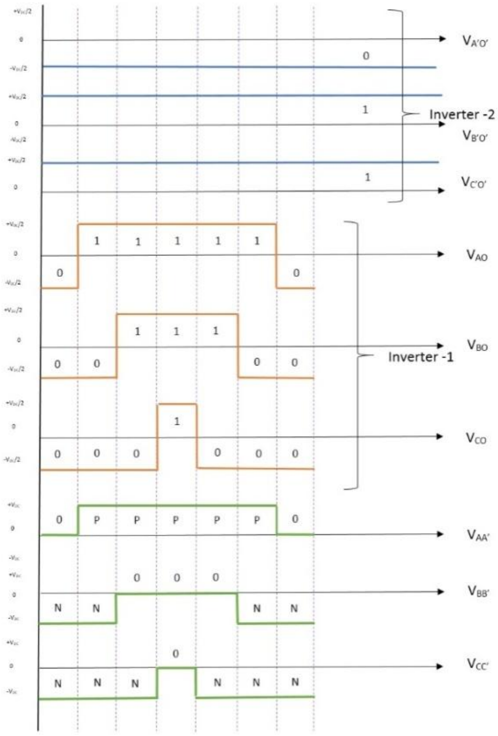

Fig. 7 Inverter-2 pole voltages, Inverter-1 pole voltages and phase voltages for undermodulation mode II (sector A, sub-sector 2)

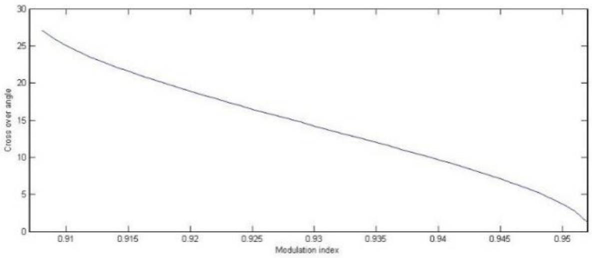

Fig. 8 Crossover angle (θ) v/s modulation index m

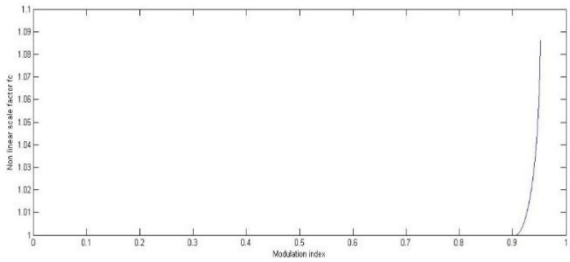

Fig. 9 Non-linear scale factor (fc) v/s modulation index (m)

C. Over modulation mode-I

The principle of over modulation for 2 level SVM was first proposed in [15]. The over modulation region starts when the reference Voltage vector surpasses the outer hexagon edge. The operation of 2 level Space Vector Modulation in over modulation modes has been explained in [16]. The operation of a 3 level over modulation of SVM has resemblances with the 2 level over modulation. Because of the symmetry of operation of over modulation for all sectors, in this paper we will discuss only one sector i.e sector A. The operation will remain same for remaining 5 sectors. Fig. 4(b) shows the operation of 3 level SVM in over modulation mode I. The ref. vector crosses hexagon side at 2 places. A modified ref. vector is selected to compensate for the loss occurring in the fundamental vector. This modified ref. V_m remains partially on the circular trajectory and partially on the hexagon. The circular path is shown by the arc ab and de has larger radii $V_m (V_m > V^*)$ and cuts the hexagon side at a crossover angle of θ , as shown is Fig. 4(b) [14-17].

For simplification, a nonlinear scale factor can be used to extend the under modulation mode to over modulation Mode-I. The nonlinear scale factor can be given as [15]:

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$$f_c = \frac{V_m}{|V^*|} \quad (3)$$

Where V_m is the magnitude of new extended reference in case of overmodulation mode 1, $|V^*|$ is the magnitude of reference voltage. For the purpose of finding the curve for nonlinear scale factor and crossover angle a MATLAB code was written and curves were plotted and saved as lookup table. Fig. 9 shows the plot of fc v/s modulation index and Fig. 8 shows the plot of crossover angle v/s modulation index.

II. SIMULATION

The simulation of Three level SVM using OEWIM was carried in PSIM. Fig. 10 shows the schematic of the simulation carried out. The switching frequency has been set to 3 kHz. For simplicity a three phase balanced RL load (R=0.23Ω and L=30.7mH) is taken as load. Using lookup table for nonlinear scale factor (fc) the operation of SVM is extended to overmodulation mode-1.Fig. 11-Fig. 13 shows the output of the inverter for various cases along with their FFT.

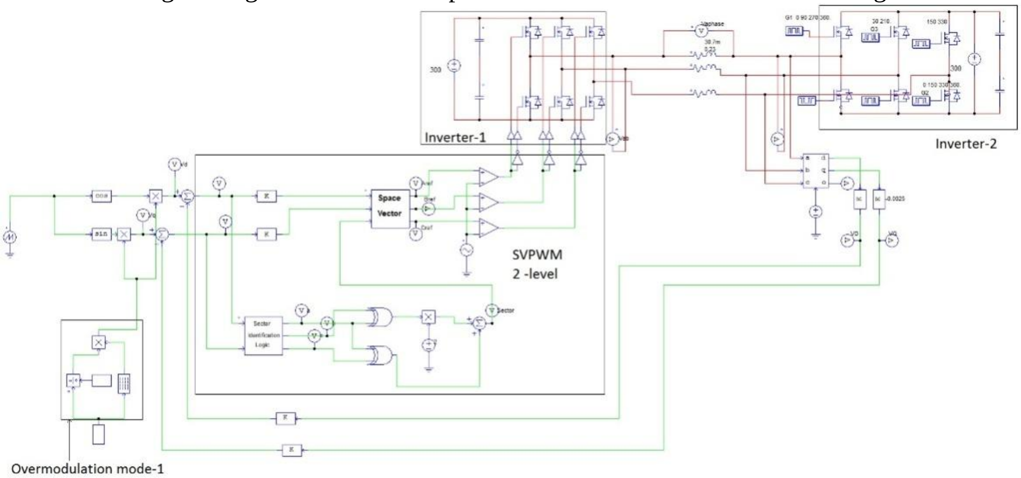
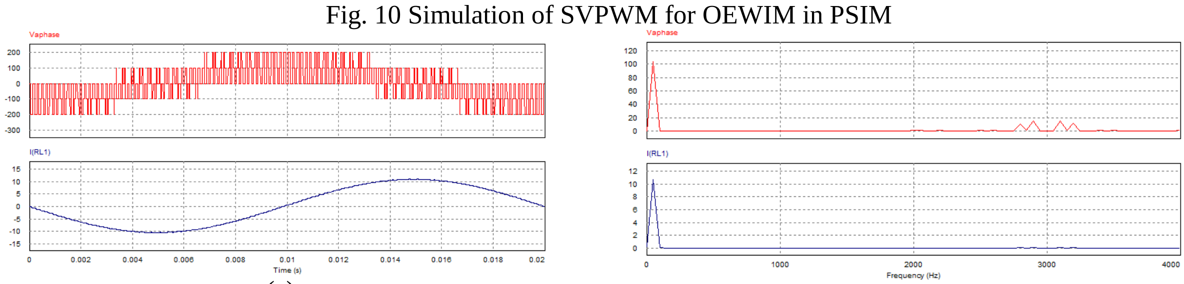


Fig. 10 Simulation of SVPWM for OEWIM in PSIM

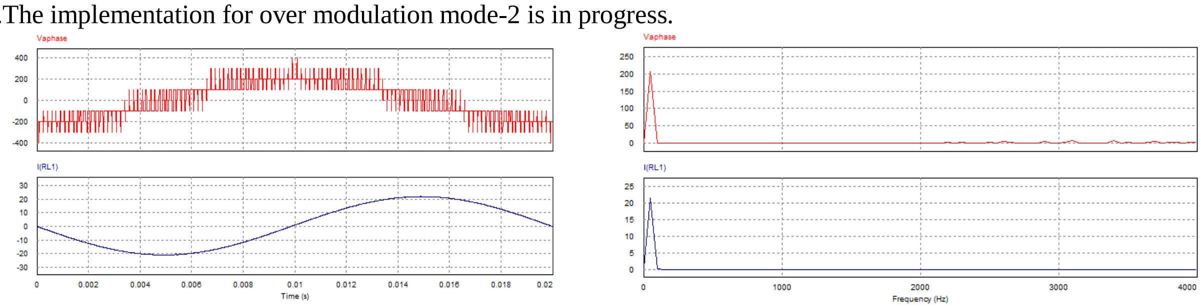


(a) (b)

Fig. 11 (a) Phase Voltage and current for under modulation mode – I (m=0.3) (b) FFT for Phase voltage and current (m=0.3)

V. CONCLUSION

The Space Vector Modulation for OEWIM has been implemented successfully using PSIM software. SVM implementation of OEWIM has been done without the use lookup tables and sector identification logic unlike in case of NPC inverter. In this paper though a constant frequency operation and a RL load has been used, the operation can be implemented for a motor load with v/f control. Also the operation of SVM is extended up to over modulation mode-1.The implementation for over modulation mode-2 is in progress.



(a) (b)

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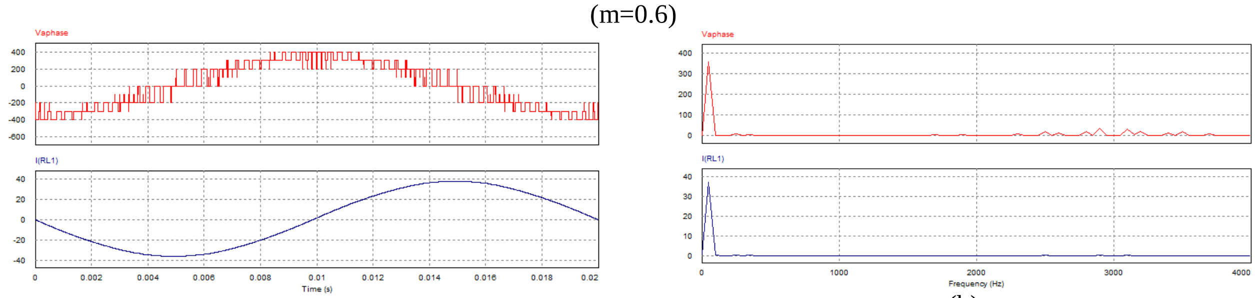
Fig. 12 (a) Phase Voltage and current for under modulation mode-II (m=0.6) (b) FFT of Phase Voltage and current (m=0.6)



(a) (b)

Fig. 13 (a) Phase Voltage and current for over modulation mode-I (m=0.94) (b) FFT of Phase Voltage and current

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DOI 10.17148/IJIREEICE/NCAEE.2016.01