FFT ANALYSIS OF AC CHOPPER FED SINGLE PHASE INDUCTION MOTOR DRIVE

M. NARENDRA KUMAR
Research Scholar, JNTU HYDERABAD
narendrakumar_maddargi@yahoo.com

P.SUJATHA
Dept. of Electrical Engineering, JNTU College of Engineering, Anantapur, India
psujatha1993@gmail.com

Dr. K.S.R. ANJANEYULU
Director (R & D), JNTU, Anantapur, India
ksralu@yahoo.co.uk

Abstract: The aim of this work is to compare the harmonic spectrum of single switch, two switches and four switches AC chopper fed drives. This paper compares FFT spectrum of current in various types of choppers controlling the single phase induction motors. MOSFET based AC chopper is considered for the control of induction motor. Digital simulation is performed using Simulink and the corresponding results of FFT analysis are presented. THD of various configurations are compared.

I. Introduction:

By Energy conservation act 2001, it has become mandatory to conserve electrical power consumption in a manufacturing unit. In this competitive environment, the electricity bill costs more than 30% of raw material cost. Hence it is necessary to benchmark the unit consumption per tones of final product output. In industrial complexes, many induction motors may often be running at no or low partial loads. Irrespective of the load conditions, these motors are however always connected to the mains. Due to the applied rated voltage at stator terminals, rated iron losses have to be supplied constantly to the motors. If it were possible by means of an additional switching device to reduce the terminal voltage of induction motors at no and low partial load, some electrical energy can be saved. The three phase large induction motors have high efficiency at less than 50% load. Experiments revealed that there can be very little advantage in using an energy saving algorithm on anything other than a small inefficient motor.

The AC Voltage regulator is used as one of the power electronic systems to control the output AC voltage for power ranges from a few watts (as in light dimmers) up to fraction of megawatts (as in starting systems for large induction motors) phase-angle controlled line-commutated voltage controllers and integral-cycle control of thyristors have been traditionally used in these type of regulators. Some techniques offer such advantages as simplicity and the ability of controlling a large amount of power economically. However, they suffer from inherent disadvantages such as retardation of the firing angle, causing a lagging power factor at the input side, in particular, at large firing anlges,and high low-order harmonic contents in both load and supply voltages/current.

Moreover, a discontinuity of power flow appears at both the input and output sides.

The recent developments in the field of power electronics make it possible to improve the electrical power system utility interface. Line-commutated AC controllers can be replaced by pulse width modulation(PWM) AC chopper controllers, which have better overall performance, and the above problems can be improved if these controllers are designed to operate in the chopping mode [3]-[7]. In this case, the input supply voltage is chopped into segments, and the output voltage level is decided by controlling the duty cycle of the chopper switching function. The advantages to be gained include nearly sinusoidal input- output current/voltage waveforms, better input power factor, better transient response, elimination of the low order harmonic and consequently smaller input output filter parameters [8],[9] & [15].

However, little attention has been given to the input power factor of AC chopper controllers [10],[16]-[18]. Other [19] insisted that the input power factor can be made to coincide with the load power factor and that it is independent of the duty cycle. In fact this claim is not true from the practical and theoretical points of view due to the higher order harmonic contents in the line current resulting from the nature of the switching processes, in particular, at low values of duty cycle. On the other hand, control by switching is often accompanied by extra losses due to the switching losses. The reduction in the number of switches is essential for control simplicity, Cost, reliability, and high switching frequency with good efficiency [16], [17].

This paper describes a symmetrical PWM AC chopper voltage controller for single phase systems. The modulated chopper switch is placed across a diode rectifier bridge connected in series with the load and a parallel switch is connected for the freewheeling purpose. This AC Chopper is more economical, owing to a smaller number of controlled switches and fewer switching losses. The literature [3]-[10], [11],[12],[15]-[20] does not deal with harmonic reduction PWM Controlled AC Chopper. In this work, an attempt is made to reduce harmonics using AC chopper

II Circuit Description

Fig1 shows the circuit configuration of the single-phase symmetrical PWM AC chopper. This circuit has the following characteristics. The circuit can operate

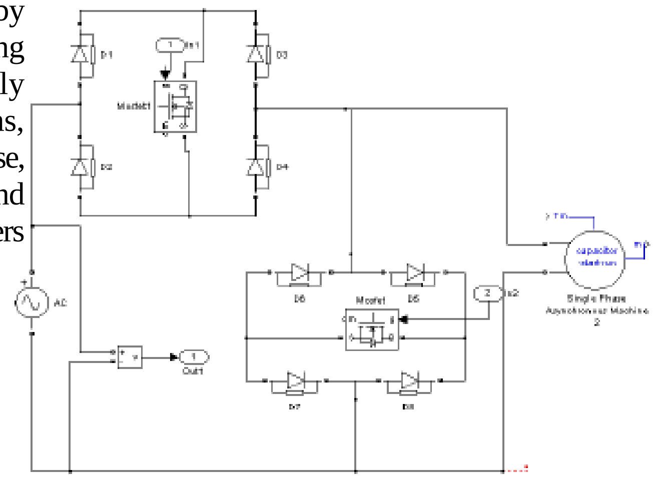

Fig. 1 AC Chopper circuit using two switches

directly from a single-phase line. The voltage across each switch is limited to the line voltage and the number of switches has been reduced to two. In the present scheme, the power circuit is composed of a DC chopper switch S across a diode bridge rectifier connected in series with the load and one switch connected in parallel with the load. The series-connected switch S_1 is used periodically to connect and disconnect the load to the supply, i.e. it regulates the power delivered to the load. The parallel switch S_2 provides a freewheeling path for the load current to discharge the stored energy of the load inductance when the series switch is turned off. The basic reason to use diodes is to enable it to be used in a circuit where a reverse voltage is encountered and to complete the freewheeling current paths. The present paper uses MOSFET as controlled switches based on equal PWM technique in constant pulse width method.

When the supply voltage and the load current are of equal polarity, normally switching takes place, in which switch is completely turned on. Since only a single switch is modulated due to the fact that a single freewheeling switch is turned on during the majority of the time period of the voltage source, the switching losses are significantly reduced and, consequently high efficiency can be approached.

The operation is divided into two modes. They are active and freewheeling modes. The active mode is defined when the modulated switch S is turned on. During the active mode, the inductor current is forced to flow through the voltage source via the modulated switch S during its on-state period.

Single Phase Induction Machine (SPIM) is most widely used than other machines due to their advantages such as simplicity in construction, reliability in operation, lightness and cheapness. The speed control of such motors can be achieved by controlling the applied voltage on the motor by the use of power electronic devices. The AC line commutated phase angle control or integral cycle control with thyristor technology has been widely used in the voltage regulators. They suffer from several disadvantages such as retardation of firing angle, enormous harmonics in motor and supply current, discontinuity of power flow to the motor..

The symmetrical pulse width modulated control technique for AC choppers control the motor voltage by varying the duty cycle is discussed in [15]. The AC power is adjusted by a circuit which uses four switches and examines the fundamental character of the circuit [16]. A novel drive for single phase induction motor has an attractive feature that it effects both frequency and phase angle simultaneously [13].

Improved circuit of AC Chopper for single phase systems use only a single pulse width modulated switch. The advantages of this system are simple design requirements, easy implementation and high power capacity. Power factor improvement of AC Chopper using symmetrical and asymmetrical pulse width modulation is discussed in [17] and [20]. A pulse width modulated buck boost AC chopper which solves commutation problem and gives good steady state performance is discussed in [18]. Optimal harmonic reduction in AC/AC chopper converter is discussed in [19]. Improved circuit of AC Chopper system is given in [20]. The above literature does not deal with the comparison of THD in PWM AC Chopper system with phase controlled AC Chopper system. In this paper, an attempt is made to compare the THD in the two systems.

Four Switch PWM AC Chopper

The circuit shown in Fig.2 is a PWM AC Chopper for single phase system. It consists of four switches. The series switches S_1 and S_4 are used to connect and disconnect the motor terminals to the supply. The series switches S_3 and S_2 provide a freewheeling path. A diode connected in anti-parallel with each parallel switch is used to complete the freewheeling current paths. Gating of these switches based on equal PWM technique or constant pulse width method is efficient and simple to implement

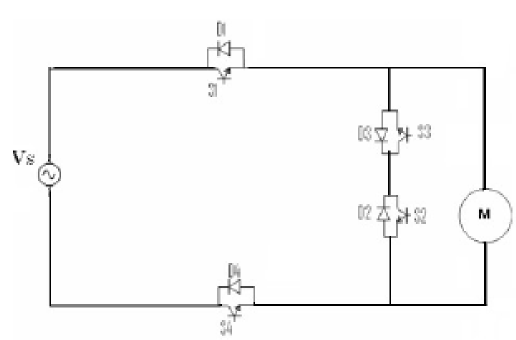

Fig.2 Circuit diagram of pulse width modulated AC Chopper.

When the source voltage is positive, switches S_3 and S_4 are turned on and S_2 is controlled by PWM. By turning S_1 on, current flows from source to the load

Table1. Switching sequence

	S_1	S_2	S_3	S_4
VS>0	PWM	PWM	ON	ON
VS<0	ON	ON	PWM	PWM

When the source voltage is negative, switches S_1 and S_2 are turned on and switches S_3 and S_4 are controlled by PWM. The control method for positive and the negative period of the source is shown in Table 1.

The pulse generation circuit is shown in Fig 3. The generation of driving signals is accomplished by using the following control circuit.

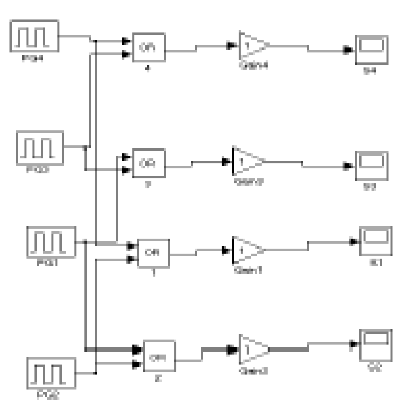

Fig.3 Pulse Generation circuit

The equation for the RMS output voltage is

$$V_0 = Vs\sqrt{n/(m+n)} = Vs\sqrt{K}$$

n-No. of cycles for which load is connected

m-No. of cycles for which load is disconnected

Average device current is KI_m/Π

RMS device current is $I_m\sqrt{K/2}$

III. Modes of Operation

The operation modes are divided into three modes as given below .

1. Active mode
2. Freewheeling mode
3. Dead time mode

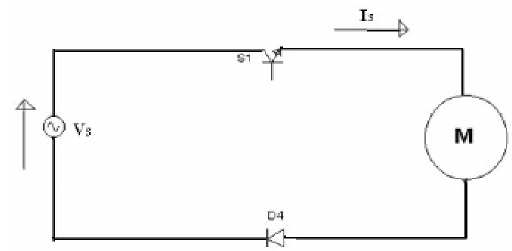

Fig. 4a. Equivalent circuit for Active Mode

The Fig 4a shows an equivalent circuit for active mode of the positive half cycle. This represents the on state period of switches S_1 and S_4. When $i_m > 0$, the motor current i_m flows through the switch S_1 and the body diode of the switch S_4. The equivalent circuit of freewheeling mode for the positive half cycle is shown in Fig. 4b.

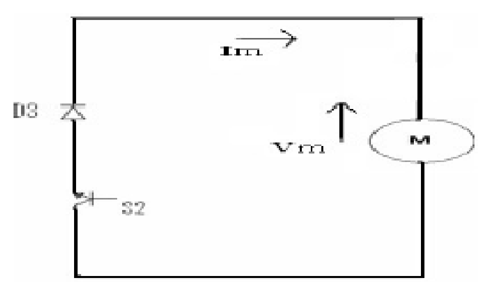

Fig. 4b Equivalent circuit for Freewheeling Mode.

This mode represents the off- state periods of the switches S_1 and S_4 . During this the motor terminals are isolated from the supply and stator is short circuited.

During positive half cycle, S_2 and the body diode D_3 are conducting. The motor terminal voltage is zero and the current naturally decays through freewheeling switches.

Fig.4c shows an equivalent circuit for dead time mode of the positive half cycle.

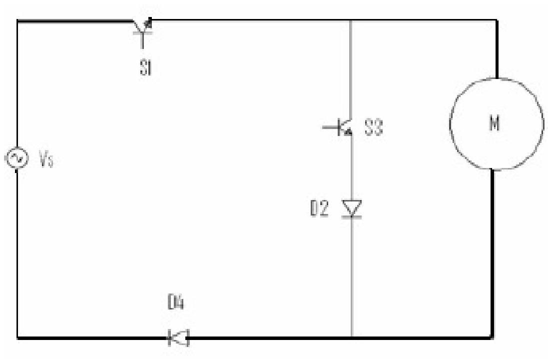

Fig. 4c Equivalent circuit for dead Time mode

This mode is provided to avoid the voltage and current spikes. During the positive half cycle, switches S_2 and S_4 are turned on for safe commutation

IV. Simulation Results:

AC chopper fed Induction motor using single switch is shown in figure 5a.The equivalent circuit model of single phase induction motor based on double field revolving theory is used for simulation. The spectrum is obtained for the current drawn by the motor. The FFT analysis for output current with 40% pulse width is shown in figure 5b. The THD is 64.19%. The FFT analysis with 60% pulse width is shown in figure 5c. The corresponding value of THD is 27.6%. The FFT analysis with 70% pulse width is shown in figure 5d. The corresponding value of THD is 13.98%.

Two Switch AC Chopper fed induction motor system is shown in figure 6a. The FFT analysis for the output current with 40% pulse width is shown in figure 6b. The THD is 69.52%.The FFT analysis with 60% pulse width is shown in figure 6c. The corresponding THD is 43.93%. The FFT analysis with 70% pulse width is shown in figure 6d. The corresponding THD is 37.31%.

AC Chopper system using four Switches is shown in figure 7a. Control switch is implemented with two switches in the lines. Freewheeling switch is implemented with two switches in parallel with the load. FFT analysis for output current with 40% pulse width is shown in figure 7b. The THD value is 78.54%. The FFT analysis with 60% pulse width is shown in figure 7c. Value of THD is 61.45%.The FFT analysis with 70% pulse width is shown in figure 7d and the value of THD is 55.04%.

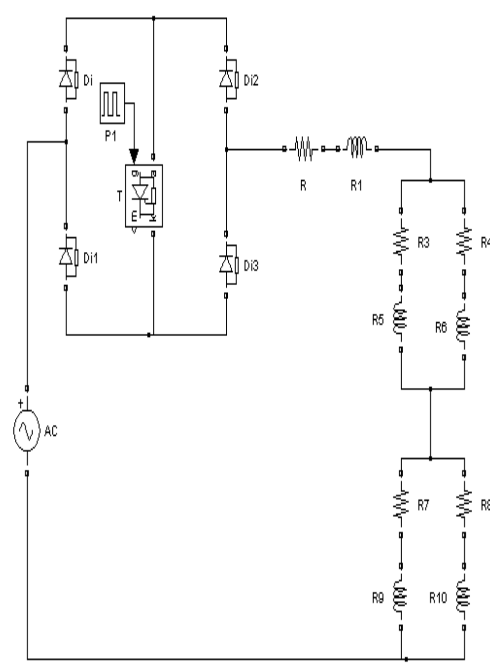

Fig. 5a AC Chopper Fed Induction Motor using Single switch

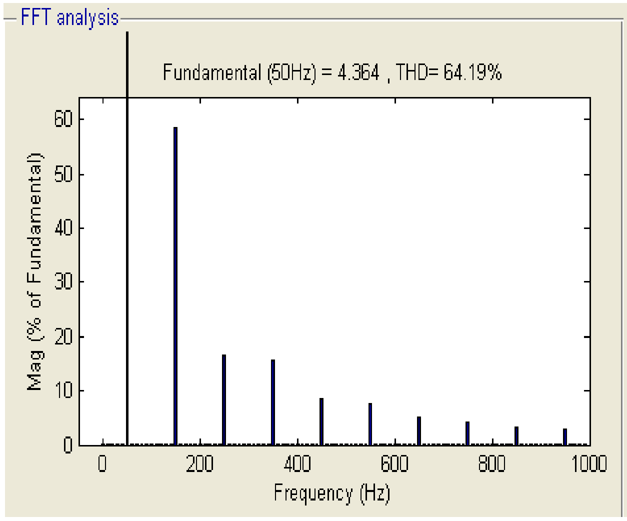

Fig. 5b FFT analysis of output current with 40% pulse width

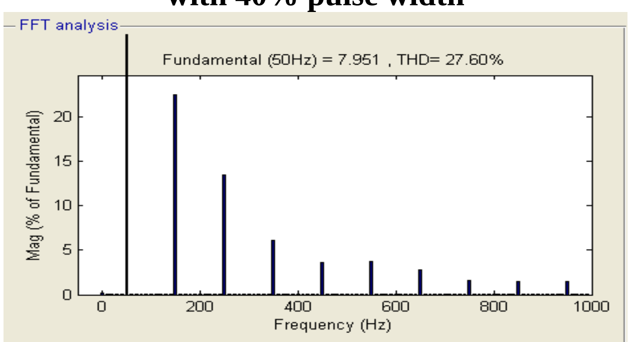

Fig. 5c FFT analysis of output Current with 60% pulse width

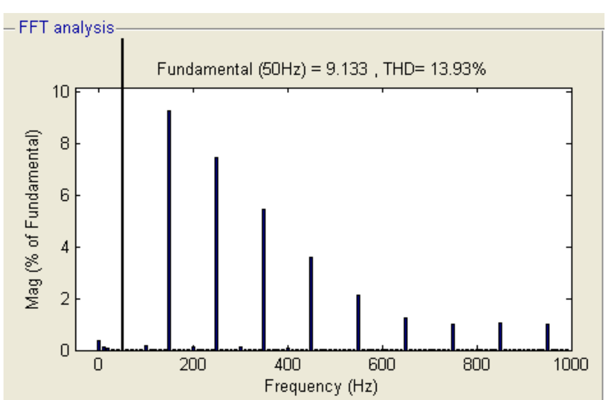

Fig. 5d FFT analysis of output current with 70% pulse width

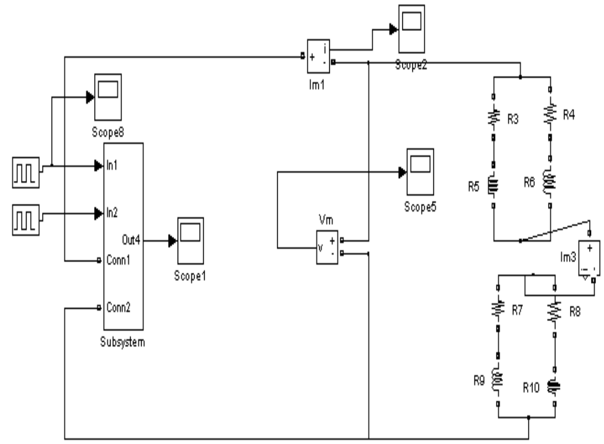

Fig. 6a Two Switch A C Chopper Fed Induction Motor

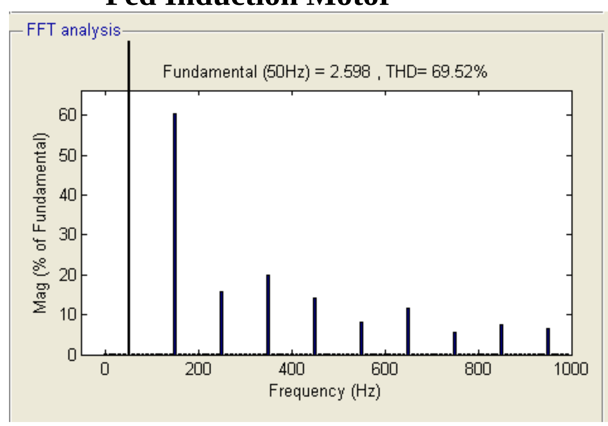

Fig. 6b. FFT analysis of output current with 40% pulse width

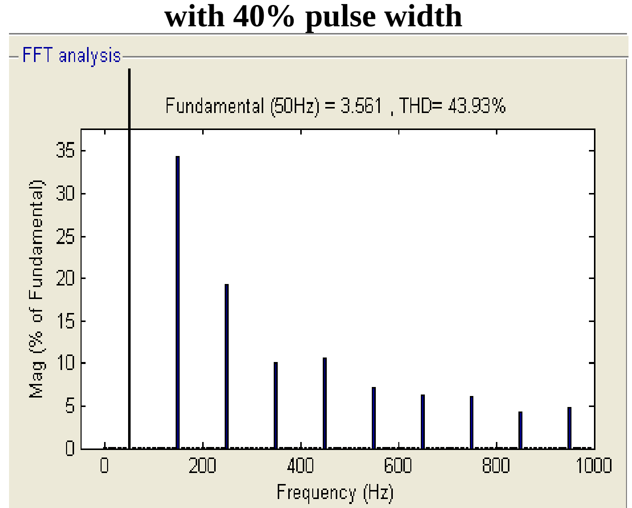

Fig. 6c FFT analysis of output current with 60% pulse width

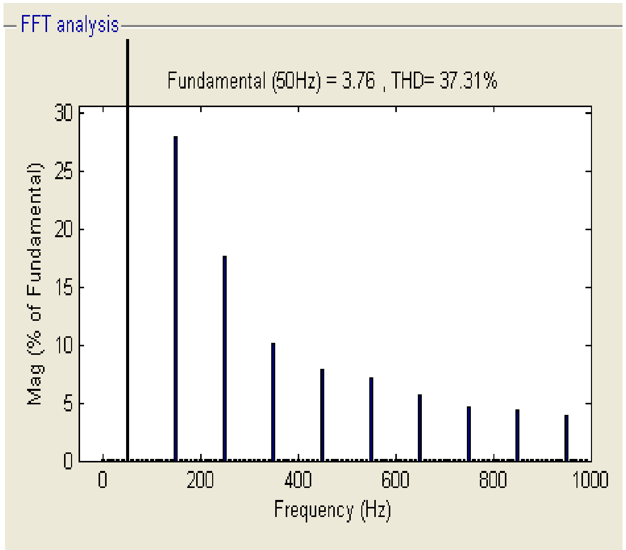

Fig. 6d FFT analysis of output current with 70% pulse width

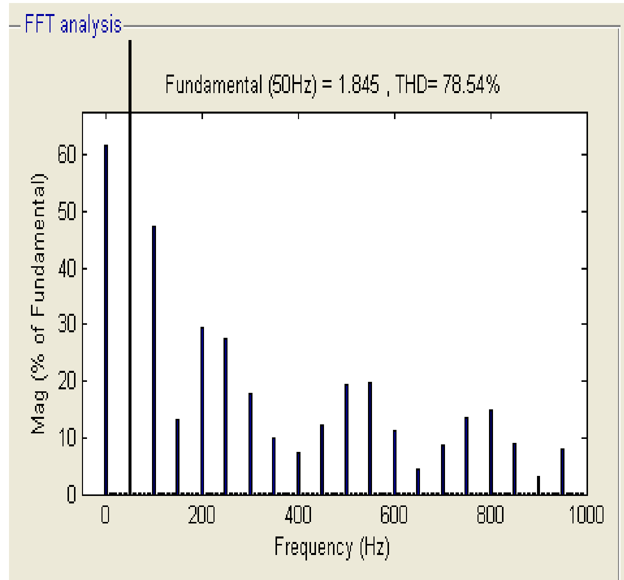

Fig.7b FFT analysis of output current with 40% pulse width

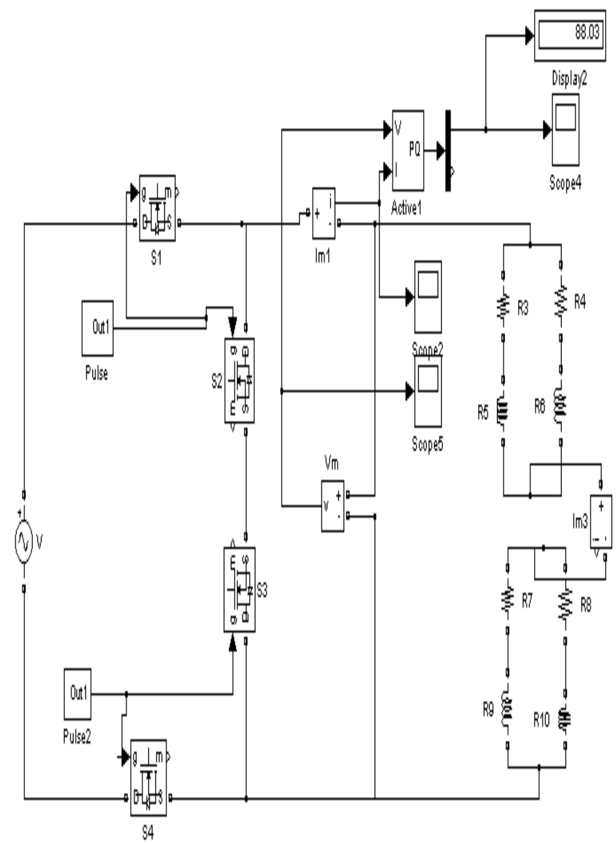

Fig. 7a. A C Chopper system using Four Switches

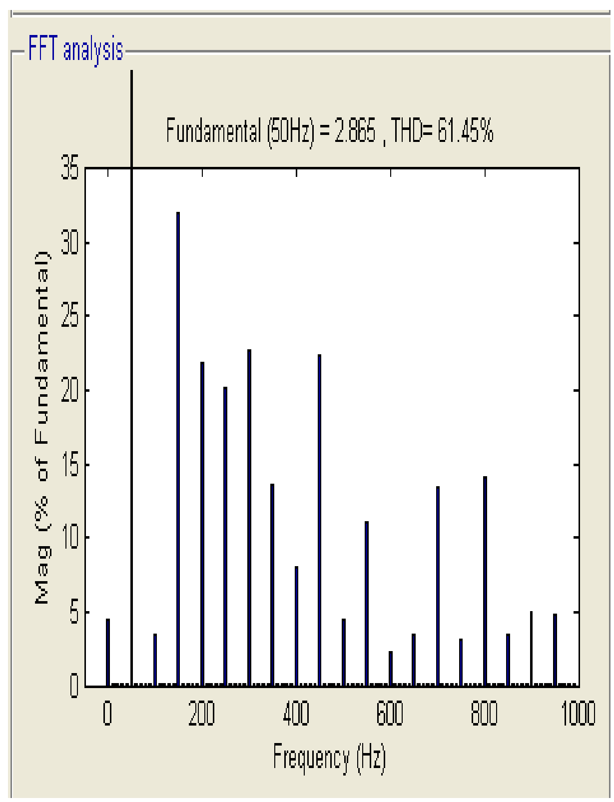

Fig. 7c FFT analysis of output current with 60% pulse width

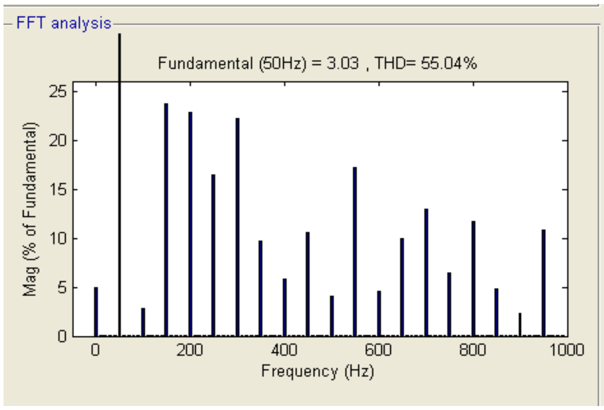

Fig. 7d FFT analysis of output current with 70% pulse width

Pulse width	THD in 1 – switch AC Chopper	THD in 2 –switch AC Chopper	THD in 4 –switch AC Chopper
40%	64.19	69.52	78.54
60%	27.62	43.93	61.45
70%	13.93	37.31	35.04

From Table 1, it can be seen that the THD in AC chopper using single switch is less.

V. Conclusion

The Simulink models for the Pulse Width Modulation AC Choppers are developed and they are used for simulation studies. FFT analysis was done for various values of pulse width. It is observed that the THD value decreases with the increase in the pulse width. The simulation results indicate that THD of the output current is minimum in the case of AC Chopper using single switch. This configuration may be preferred since it has reduced hardware and improved performance. The improvement in the performance is due to the reduction in the harmonic content of stator current. Thus the Pulse width modulated AC Chopper can be used for speed control, energy saving and harmonics reduction in AC Chopper fed induction motor drives.

References:

[1] Basanta B.Palit, "Energy saving operation of induction motors by voltage reduction at no load and low partial load",Basle institute of technology ,IEEE 1989.

[2]Sant.M.T. "Energy conservation using AC variable frequency drives",Siema newsletter,2004.

[3] B.W. Williams," Asymmetrically modulated AC Choppers" IEEE Trans. Ind. Electron, vol. IE-29, pp.181-185, Aug. 1982.

[4] S.A. Bhat and J.Viyhayathil,"A simple multiple pulse width modulated AC chopper,"IEEE Trans. Ind. Elrctron, vol. IE-29, pp.185-189.Aug.1982.

[5] S. Iida and S. Miyairi,"Effects of PWM applied in a single-phase ac chopper control,"Trans.Inst. Elect. Eng. Jpn, vol.103-B, no. 1, pp. 7-14, Jan.1983.

[6].Roy, P.Poitevin, and Olivier," A Comparative study of single-phase modulated AC Choppers,"IEEE Trans. Ind. Applicat., vol. IA-20, pp. 1498-1506, Nov. /Dec. 1984.

[7] G.H. Choe, A.K. Wallace and M.H. Park," An improved PWM technique for AC Choppers,"IEEE Trans. Power Electron., vol.4, pp.496-505, Oct.1989.

[8]S.A. Hamed,"Steady-State modeling analysis. and performance of transistor controlled AC power conditioning." IEEE Trans. Power Electron., vol.5, pp.305-313, July 1990.

[9] D.A. Deib and H.W.Hill," Optimal harmonic reduction in AC/AC chopper

converters," in Proc. IEEE PESC'93, 1993, pp.1-9.
[10] M.Mazzuccheli, L.Puglisi, G Sciutto, and P. Tenti,"Improving the performance of AC/AC static converters with high frequency AC Chopper control," in Proc. Powercon 9,1982,vol.I-3.pp.1-9.
[11] N.A. Ahmed, K.Amei, and M.Sakui," A Symmetrical PWM AC Chopper controller fed single – Phase induction motor," in Proc. AL-Azhar 5th Int. Conf. (AEIC'97), Cairo, Egypt, Dec. 19-22, 1997,pp 123-134.
[12] G.Joos and P.D. Ziogas," A PWM AC Controller-high current power supply," in Proc. IEEE Iecon'92, pp. 554-559.

#[13]Abdel-rahim G.M.,Ahmed N.A.,Makky A-R.A.M. ,"A novel AC Drive with single-phase induction motors",IEEE Trans.on Ind. Election. 42(1), 1995, pp 33-39.
[14]Ahmed N.A., Amei K., Sakui M., "improved circuit of AC Choppers for single phase systems", Proceedings of Energy conversion conference, PCC'97,Volume 2, 3-6 Aug. 1997,pp 907-912.
[15]D.H. Jang ,J.S. Won and G.H.Choe, "Asymmetrical PWM Methods of AC Chopper with improved input power factor" ,in proc. IEEE PESC'91, 1991, pp 838-845.
[16]L. Salazar, C.Vasquez, and weichmann, "on the characteristics of a PWM ac controller using four switches", In Proc. IEEE PESC '93.1993 .pp 307-313.
[17]P.D. Ziogas, D.Vincenti,and D. Joos, "A Practical PWM AC chopper topology," In Proc. IEEE IECON'91,1991 ,pp 880-887
[18]K.E. Addoweesh and A.L. Mohamadein, "Microprocessor based harmonic elimination in chopper type AC Voltage regulator," IEEE Trans. Power Electron, Vol. 5,pp 191-200, Apr-1990
[19]B.H. Kwon,B.D.Min and J.H.Kim "Novel Topologies of AC chopper" Proc. Inst. Elect.Engg-Elect Power Applicant; vol 143 no.4 pp 323-330 July 1996.
[20]N.A.Ahmed, K.Amei and M.Sakui " Improved Circuit of A.C. Chopper for Single-Phase systems." In Proc. Energy Conversion Conf. (PCC'97),Nagaoka,Japan,Aug 3-6, 1997,pp 907-912

M. Narendra Kumar has obtained B.E. degree in Electrical Engg. from Gulberga University, M.S. from BITS and M.Tech. From JNTU Anantapur subsequently. Now he is pursuing his Research in the area of Energy Management. Presently a research scholar at JNTU Hyderabad. He is a life member of ISTE and Member of IEEE.

P.Sujatha, presently working as, Assoc .Professor, Department of Electrical and Electronics Engineering, J.N.T.U. College Anantapur,-515002, Andhra Pradesh, India She completed her B.Tech degree in 1993 and M.Tech Degree with specialization in Electrical Power Systems in 2003 from J.N.T.U.College of Engineering, Anantapur, Andhra Pradesh, India. She has nearly 15 years of teaching experience and her areas of interest include Reliability Engineering with emphasis to Power Systems and Real time Energy Management. She is currently working towards her PhD in Electrical Engineering at JNTU Anantapur.

Dr.K.S.R.Anjaneyulu, Professor of Electrical & Electronics Engineering presently working as Director, R&D, J.N.T.U, Anantapur, Andhra Pradesh, India. He has completed his B.Tech Degree in 1982, M.Tech Degree in February 1985 and Ph.D. in 1999. He has 23 years of teaching research experience and his areas of interest include Power systems, Facts devices, Neuro-Fuzzy system and drives.