

Real Time FPGA Implementation of PWM Chopper Fed Capacitor Run Induction Motor

N. Murali¹, V. Balaji²

¹Department of Electrical and Electronics Engineering, SCSVMV University, India

²EEE, Saveetha School of Engineering, Saveetha Institute of Medical & Technical Sciences, India

Article Info

Article history:

Received Aug 12, 2018

Revised Oct 13, 2018

Accepted Oct 27, 2018

Keyword:

Efficiency

Harmonics

Modulation index

Power factor

Pulse Width Modulation

ABSTRACT

This paper presents the performance enhancement of capacitor run induction motor by pulse width modulated AC chopper. The phase angle control faces severe shortfall in the performance improvement for larger triggering angles. In this paper the comparison of phase angle control and sinusoidal pulse width modulation technique is encountered for effective speed control of single phase capacitor run induction motor. The necessary parameters are taken into considerations are higher efficiency, lesser total harmonic distortion and high input power factor. The results are compared by using the simulations using matlab Simulink environment. The validation of result in hardware is implemented using Field programmable gate array for sinusoidal pulse width modulation technique.

Copyright © 2018 Institute of Advanced Engineering and Science.

All rights reserved.

Corresponding Author:

N. Murali,

Department of Electrical and Electronics Engineering,

SCSVMV University, India.

Email: muralibee@gmail.com

1. INTRODUCTION

Single phase induction motor drives play a significant role in domestic and industrial applications. The speed control of induction motor is widely used in all applications. All the industries prefer single phase induction motor compared to other motor drives due to less cost, simpler control circuits and less maintenance. The conventional method utilizes integral cycle control and phase control for controlling the speed. In integral cycle control the single phase induction motor is controlled but due to sub harmonics causes lumps in torque speed characteristics [1]. The merits of conventional control are low cost and easier control. The demerits of conventional control are poor power factor, high harmonic distortion and non-sinusoidal voltage at the input. The speed control of capacitor run induction motor drives fed from AC chopper utilizes different topologies of phase control methods. The semiconductor device TRIAC is connected in the main winding, TRIAC connected in auxiliary winding of motor and anti-parallel thyristors are connected to the input supply. The phase control is better compared to single pulse width modulation, it is shown that efficiency is slightly better in phase control than single pulse width modulation technique. The literature shows that multiple pulse width modulation gives better quality output than phase control method. The performance is determined by good input power factor, less total harmonic distortion of current and voltage and improvement in efficiency. The sinusoidal pulse width modulation technique is utilized for effective speed control and improvement in performance parameters. In the literature TRIAC connected in auxiliary winding gives better output at lower triggering angles. At larger triggering angles the power factor is poor, harmonic distortion value is more and non-sinusoidal waveform at the input. TRIAC connected in auxiliary winding of motor is not suitable for speed control due to the unstable operation at certain triggering angles [8]. The merits of pulse width modulation AC chopper is high efficiency, less harmonic contents,

effective braking operation and improved power factor [2]. The commonly used configuration of AC-DC-AC which are used in variable speed drives, FACTS controller and wind turbines are replaced by AC-AC converter without DC source [3]. The turns ratio of single phase induction motor is treated as complex quantity and the corresponding performance parameters are computed [4]. The topology used is symmetrical AC voltage controller which utilizes three switches. The performance is effective for dimmer loads and induction heating, but the lower order harmonics is present in the output voltage [5]. PWM chopper requires second order filter for effective performance under closed loop control. The closed loop control with filter reduces the fluctuation due to load variations [6]. The capacitor run induction motor is used as braking using triac ac voltage controller. The inhibiting pulses of rectifier are a failure compared to disconnection of auxiliary winding [7].

AC voltage regulation is important aspect in industry and domestic applications. The new mathematical model is derived and low cost model. The controller is checked effectively with I and PI control mechanisms [9]. The drawback of AC to AC converter with phase control is at higher firing angles the output waveform is non-sinusoidal and poor power factor. This paper compares the conventional controller with extinction angle control and sinusoidal pulse width modulation [10]. PWM method is better than phase angle control and the converter produces low order harmonics at higher conduction angles [11]. The converter is connected with capacitor bank to reduce the total harmonic distortion. At higher conduction angles the distortion factor increased due to load [12]. The resonant dc link converter operates at zero voltage and zero current switching leads to more efficient. Compared to hard switching the delayed triggering angle control gives better output and utilizes the passive load at the output [13]. The harmonic elimination is done through sinusoidal pulse width modulation and gratifies through the amplitude and frequency modulation [14]. TRIAC control is utilized for attaining better torque characteristics for single phase induction motor and the results shows that the optimum capacitor values determines the torque and efficiency. The lower capacitor shows better performance compared to high value of capacitor. The operation is noisy due to the harmonics present in the system [15]. The TRIAC controlled single phase induction motor experiences the pulsating torque at the output. The significant reason is production of even multiples of harmonics and these can be eliminated by connecting suitable shunt resistor. The limitation of this method is the power dissipation and losses are more due to the resistance [16]. Pulse width modulation of variable speed control of fan utilizes the ac chopper. The harmonics in the output voltage is minimized by employing low pass filters. The design of control circuit components is complex and in the present paper the advanced features of triggering is used [17].

In this paper phase control of speed control method is compared with sinusoidal pulse width modulation. The operation and working principle of sinusoidal pulse width modulation is explained along with the pulse generation obtained by field programmable gate array. In the corresponding chapter the simulation results are compared between phase control method and sinusoidal pulse width modulation method. The waveforms obtained from the hardware using field programmable gate array for the sinusoidal pulse width modulation.

2. AC VOLTAGE CONTROLLER

2.1. Phase Angle Control

In phase angle control, the two silicon controlled rectifier are connected in anti-parallel is used as the topology of AC voltage controller. The output of AC voltage controller is connected to the single phase capacitor run induction motor. The triggering pulses generated for the two thyristors are alternating in nature. For the period of positive half cycle thyristor T1 is in forward bias and starts conducting when the gate signal is available, while the thyristor T2 is in reversed bias condition. At 180 degrees thyristors need to be switched off by natural commutation. But due to the motor load the current continue to flow. For the period of negative half cycle thyristor T2 is in forward bias and starts conducting when the gate signal is available, while the thyristor T1 is in reversed bias condition. At 360 degrees thyristors need to be switched off by natural commutation. But due to the motor load the current continue to flow. Bidirectional AC voltage controller as shown in Figure 1.

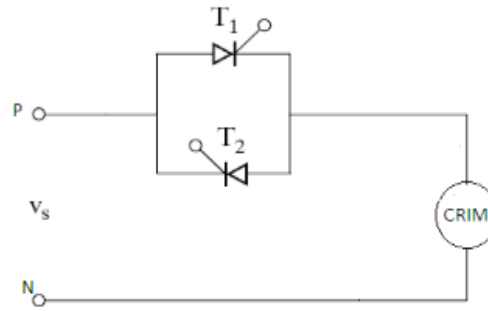


Figure 1. Bidirectional AC voltage controller

2.2. Sinusoidal Pulse Width Modulation

The AC voltage controller uses different topology for the improvement in performance parameters of capacitor run induction motor. This topology uses four diodes and main device IGBT S1 is employed for conducting in both positive half and negative half cycle. For the freewheeling action it employs four diodes and one auxiliary device IGBT S2. The triggering signal is to be generated for the main switch and freewheeling switch. For the period of positive half cycle the current flows through diode D1, switch S1, diode D4 and connected to the capacitor run induction motor and return to the supply. For the period of negative half cycle the current flows through capacitor run induction motor, diode D3, switch S1, diode D2 and connected supply voltage. For the period of positive half cycle the freewheeling action takes through the path load, D3', switch S2, D2' and back to load. For the period of negative half cycle the freewheeling action takes through the path load, D1', switch S2, D4' and back to load.

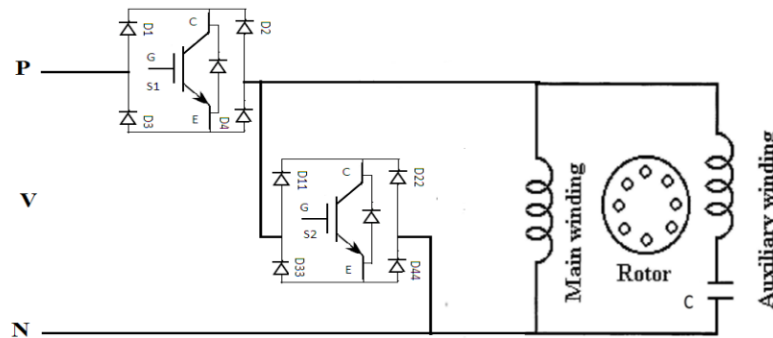


Figure 2. Sinusoidal Pulse Width Modulation AC voltage controller

The output of sinusoidal pulse width modulation AC voltage controller under ideal conditions is taken as V_o and I_o . The pulse width has two specific levels i) high level denoted by V_H and ii) low level is denoted by V_L . The low level value is considered as zero volts. V_m and I_m are corresponding maximum values of voltage and current.

$$V_o = V_m \sin(\omega t) \quad (1)$$

$$I_o = I_m \sin(\omega t) \quad (2)$$

The output voltage is expressed in Fourier series as

$$V_o(\omega t) = \frac{a_0}{2} + \sum_{n=1}^{\infty} a_n \cos\left(\frac{n\pi\omega t}{L}\right) + \sum_{n=1}^{\infty} b_n \sin\left(\frac{n\pi\omega t}{L}\right) \quad (3)$$

The term L =time period/2

The term a_0 corresponds to dc offset component and the term a_n and b_n corresponds to n^{th} harmonic frequency component.

$$a_n = \frac{1}{L} \int_{-L}^L V_o(\omega t) \cos\left(\frac{n\pi\omega t}{L}\right) d\omega t, n = 1, 2, 3.. \quad (4)$$

$$b_n = \frac{1}{L} \int_{-L}^L V_o(\omega t) \sin\left(\frac{n\pi\omega t}{L}\right) d\omega t, n = 1, 2, 3.. \quad (5)$$

For our calculations the value of L is taken as 1. The PWM signal is defined as

$$V_o(\omega t) = \begin{cases} 0, & -1 < \omega t < -D \\ V_H, & -D < \omega t < D \\ 0, & D < \omega t < 1 \end{cases} \quad (6)$$

In the analysis the even harmonic components are removed by waveform symmetry and odd harmonic components are taken into account. The generalized amplitude of harmonic component a_n is illustrated by

$$a_n = \frac{2V_H}{n\pi} \sin(\pi D) \quad (7)$$

Where D is the duty cycle and odd harmonic components $n=3, 5, 7$

The total harmonic distortion of output voltage and current is given as

$$THD_v = \frac{\sqrt{\sum_{n=3}^{\infty} V_{on}^2}}{V_1} \quad (8)$$

$$THD_i = \frac{\sqrt{\sum_{n=3}^{\infty} I_{on}^2}}{I_1} \quad (9)$$

2.3. Implementation of Sinusoidal PWM using FPGA

The pulse generation of sinusoidal pulse width modulation is obtained by field programmable gate array. The VHDL language is used to program sinusoidal pulse width modulation for AC chopper. The pulses output from FPGA kit has to be isolated from the power circuit hence the optocoupler is used for this purpose. A suitable zero crossing circuit is used to sense the zero crossing of the waveform. The power switch requires a driver circuit to enable to get correct pulse output and the necessary amplification is done through it. Figure 3 shows control circuit using FPGA.

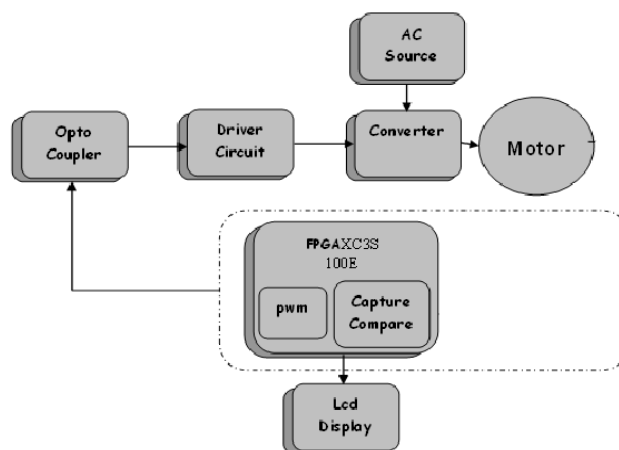


Figure 3. Control circuit using FPGA

3. RESULTS AND ANALYSIS

This sections presents performance enhancement of capacitor run induction motor using different techniques like phase angle control and sinusoidal pulse width modulation technique. The comparative analysis obtained by simulation using matlab Simulink environment. The experimental results are computed for sinusoidal pulse width modulation technique and compared with simulation results. The capacitor run induction motor is used as the load. It is exemplified by 1 Hp, 230V, 5.2 A, 1440 rpm and 12.5 micro farad as running capacitor. The motor is coupled to the mechanical load to achieve variable speed operation. The motor parameters are $R_m=7.55 \Omega$, $X_m=5.1\Omega$, $R_r=8.3\Omega$, $X_r=5.1\Omega$, $R_a=10\Omega$, $X_a=10\Omega$ and $X_{mm}=0.324\Omega$. The results are obtained for bidirectional ac voltage controller and sinusoidal pulse width modulation. The waveforms which are depicted below are efficiency, input power factor, total current harmonic distortion and total voltage harmonic distortion.

The simulation is exhibited for the TRIAC control and the Figure 4 represents variation of firing angles with power factor. The Figure 5 represents power factor versus duty cycle. It is inferred that at lower firing angles from 0 to 60 degrees the power factor is 0.8. When the firing angle increases the power factor is low. The reason is due to un-symmetric voltage and current waveforms at higher firing angles.

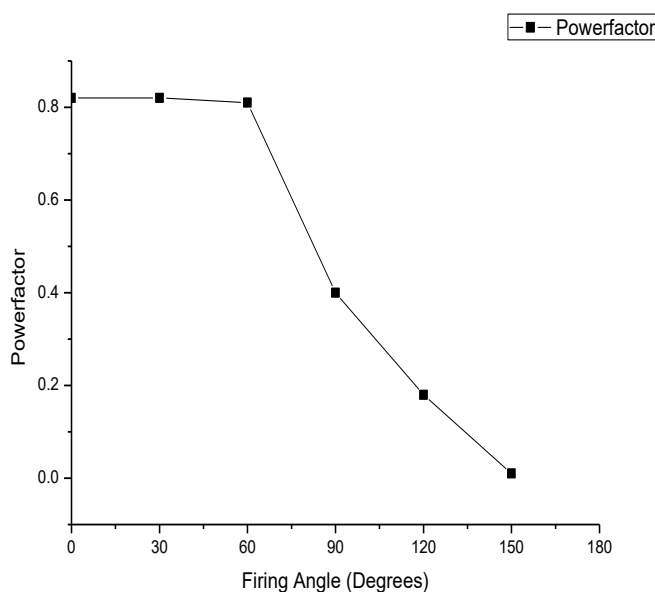


Figure 4. Powerfactor versus firing angle

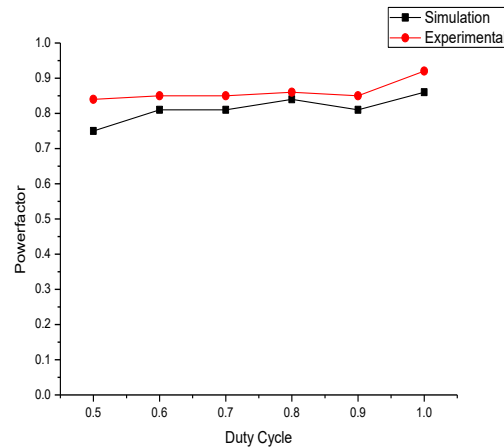


Figure 5. Powerfactor versus duty cycle

The experimental results are obtained using for sinusoidal pulse width modulation technique using FPGA. The Figure 8 represents the simulated and experimental result of sinusoidal pulse width modulation. The simulated graph is marked in black and experimental graph is obtained in red. For different duty ratio the power factor is obtained at the input of capacitor run induction motor. The power factor variations are steady at all duty cycle and slightly low at 0.5 duty cycle. It is inferred that current and voltage waveforms have lesser phase difference.

The Figure 6 is explained as motor input current of total harmonic distortion with variation in firing angles. The distortion is within the limit of IEEE standards and is exhibited till the firing angles of 60 degrees. The non-linearity in current harmonics is unveiled greater than 60 degrees. The power quality is poor due to capacitor run induction motor load, and the corresponding inductive energy requires another path to free wheel and dissipating the energy.

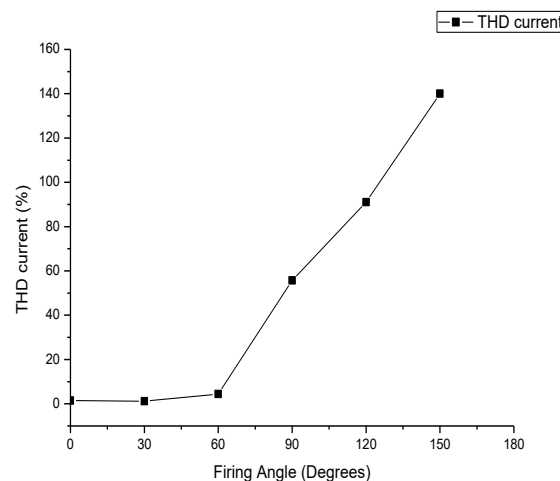


Figure 6. %THD current versus firing angle

The Figure 7 epitomizes the motor input current harmonics with respect to duty cycle of sinusoidal pulse width modulation. The simulation and experimental results are showing similar response. From the Figure 5 it is inferred that power factor decreases as the triggering angle increases. Due to the dynamic motor load when the power factor decreases the current harmonics increases to high value. The current waveforms have high distortion and leads to unsuitable for speed control as the machine derating increases. The phase control is superior till the triggering angle of 60 degrees compared to PWM control.

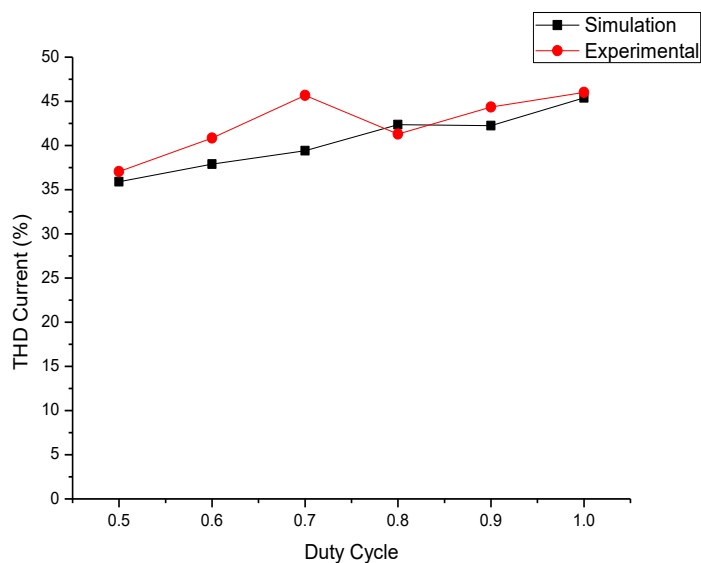


Figure 7. THD current versus duty cycle

The Figure 8 demonstrates the motor voltage harmonics of phase control method with different triggering angles. The harmonics is within the specified limits until 60 degrees and it rises to very high value due to dynamic motor load. It is subjective that current harmonics are high value due to forced commutation of the power switches in the converter. Conversely the higher order harmonics are moved to larger switching frequency and easily filtered by passive filters.

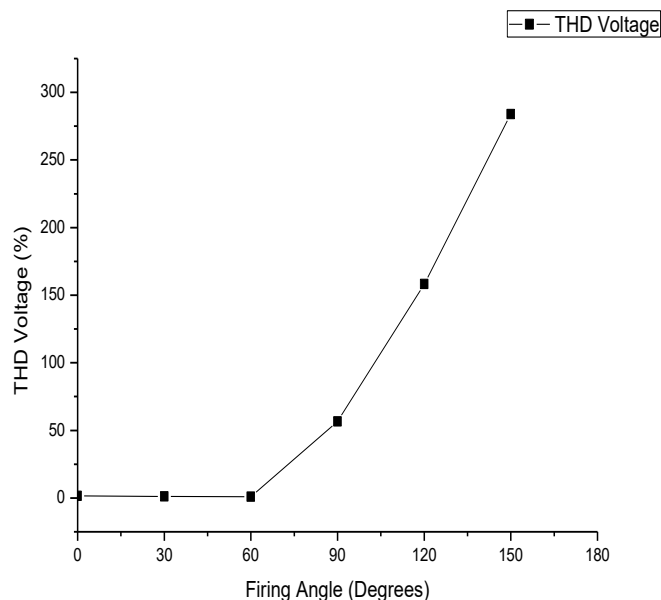


Figure 8. %THD voltage versus firing angle

The Figure 9 epitomizes the motor input voltage harmonics with respect to duty cycle of sinusoidal pulse width modulation. For higher duty cycle the amplitude of harmonic content is less. The PWM method shows better power quality than phase control.

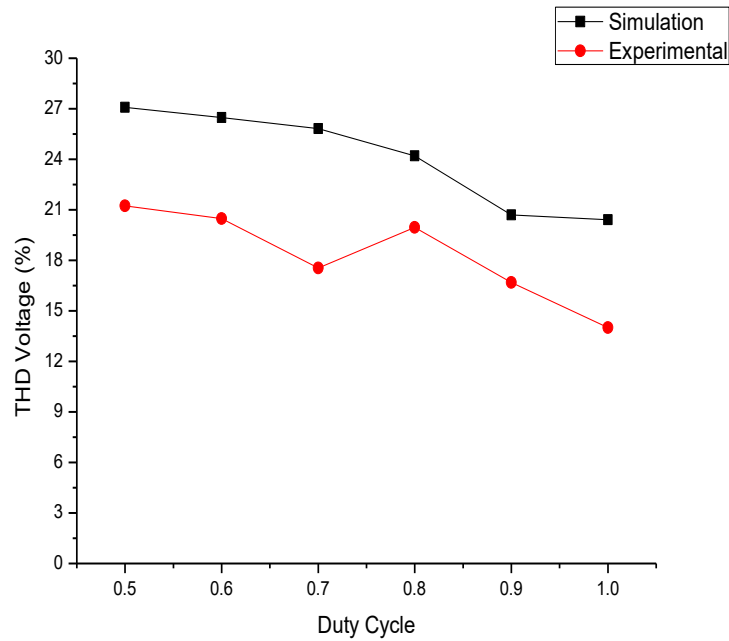


Figure 9. % THD voltage versus duty cycle

The Figure 10 portrays capacitor run induction motor efficiency for diverse triggering angles. At lower firing angles the efficiency is near 80%, but the value is lesser for higher triggering angles. The reason is due to increased copper losses at larger triggering angles.

The Figure 11 explains capacitor run induction motor efficiency for variations of duty cycle. The efficiency is near 80% for the most of the duty cycle. The efficiency is better compared to phase angle control method. The Figure 12 signifies real time experimental data obtained for the duty cycle 0.5. The sinusoidal pwm parameters are available in the Figure 12.

The Figure 13 specifies the real time spectra of total harmonic distortion of voltage waveform for the sinusoidal PWM technique. The Figure 14 specifies the experimental setup for speed control of capacitor run induction motor with FPGA control of ac voltage controller. The Figure 15 specifies the VHDL programming for pulse generation using FPGA. The programming was obtained using Xilinx platform.

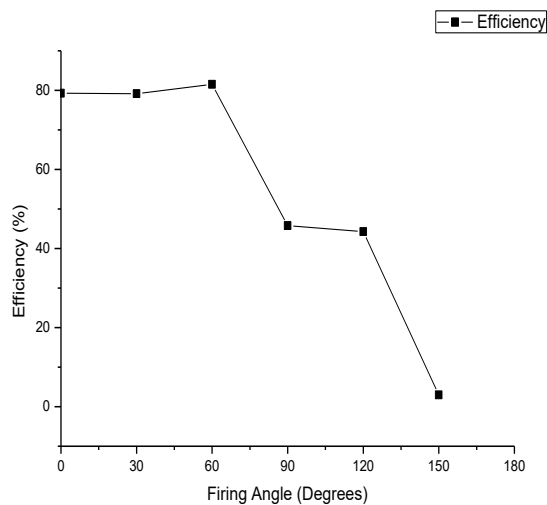


Figure 10. % Efficiency versus firing angle

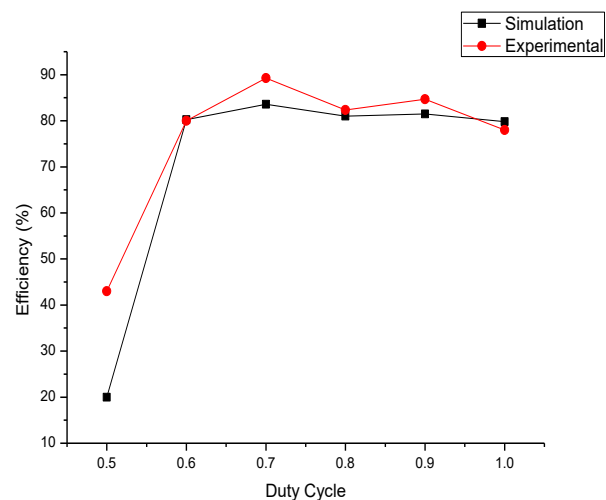


Figure 11. % Efficiency versus duty cycle



Figure 12. Experimental parameters details at 0.5 duty cycle



Figure 13. Harmonic Spectra in hardware at 0.5 duty cycle



Figure 14. Experimental setup of AC chopper fed capacitor run induction motor using FPGA

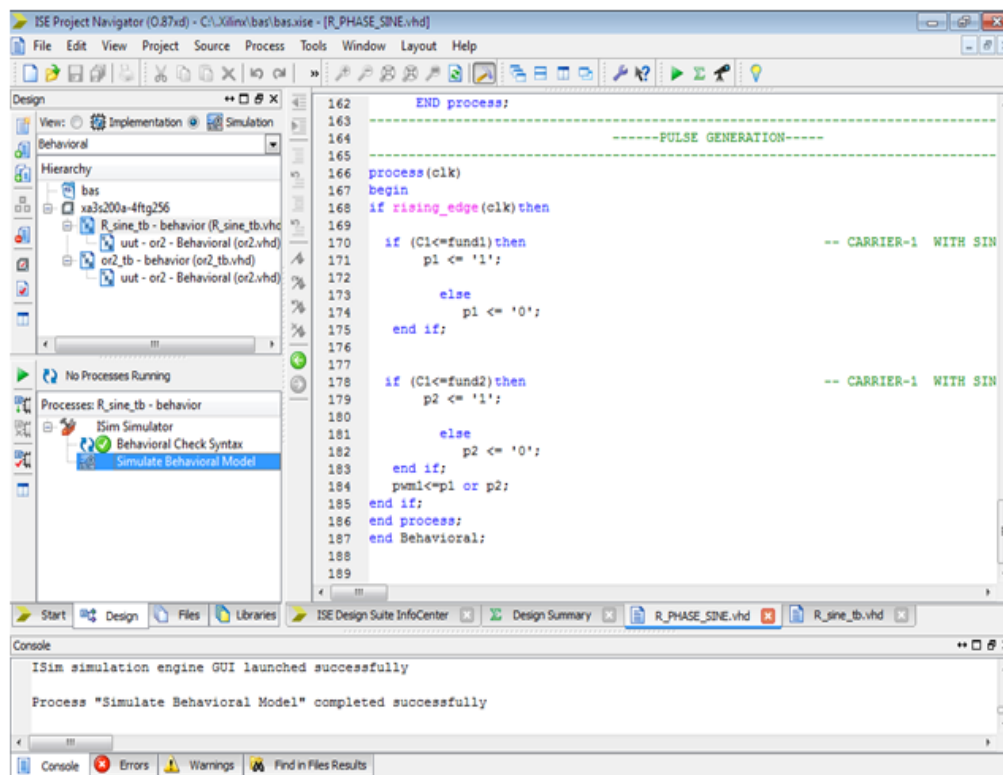


Figure 15. Pulse generation using Xilinx FPGA

4. CONCLUSION

The PWM chopper fed capacitor run induction motor is implemented in hardware using FPGA. The proposed control has improved performance parameters compared to conventional phase angle control. The efficiency and power factor has improved compared to phase angle control. The total harmonic distortions of current and voltage are slightly higher value compared to IEEE standards. This can be enhanced by suitable harmonic eliminatic techniques for the effective operation of capacitor run induction motor.

ACKNOWLEDGEMENTS

The author is presently registered PhD in SCSVMV University and like to acknowledge the support from electrical and electronics department of SCSVMV University.

REFERENCES

- [1] M.Syed Jamil Asghar., "Smooth speed control of single phase induction motors by integral cycle control ," *IEEE Transactions on Energy conversion*, vol. 14, pp. 1094-1099, Dec 1999.
- [2] M.A.Abdel-halim and A.F. Almarshoud (2011). Electronic control of Single phase induction motors using AC Choppers. *Journal of Engineering and computer sciences*, qassim university (pp 83-94).
- [3] P.Szczesniak, J.kaniewski and M.Jarnut(2015, January). AC-AC power electronic converters without DC energy storage-A review. *Energy conversion management*, Elsevier (pp 483-497).
- [4] Vijay kumar ghial, Lalit mohan Saini and Jasbir singh saini (2013). Performance prediction of energy efficient permanent split capacitor run single phase induction motor. *Journal of electrical engineering*(pp 1 -10).
- [5] Nabil A.Ahmed, Kenji Amei and Masaaki sakui(1999, October). A new configuration of single phase symmetrical PWM AC chopper voltage control. *IEEE transactions of industrial electronics* (pp 942-952).
- [6] Abdelouahab Zaatri and Souad Belhour(2014, June).Analysis and design of a PWM chopper –on/off control via a second order filter. *World journal of engineering* (pp 181-186).
- [7] K.Sundareswaran and P.Sankar (2013, July). Development of two novel power electronic circuits for dynamic braking of motors, *Electric power components and systems* (pp 1188-1204).
- [8] K.Sundareswaran "Improved energy saving scheme for capacitor run induction motor," *IEEE Transaction on industrial electronics*, Vol 48, No 1, pp. 238-240, 2001.
- [9] Liu H, Wang J and Kiselychynk .O (2016, January). Mathematical modelling and control of a cost effective AC voltage stabilizer, *IEEE Transactions power electronics* (pp 1).
- [10] S.Paramashivam and S.Muralidharan (2011, April). Analysis of AC/AC converter with enhanced power quality, *IEEE conference* (pp 179-183).
- [11] Ahmet Altintas “ A study on power quality in PWM controlled AC voltage controller”, *Scientific Research and Essays* Vol. 5(10), pp. 1075-1083, 18 May, 2010.
- [12] M.Erhan Balci and M. Hakan Hocaoglu,” Effects of source voltage harmonics on power factor compensation in AC chopper circuits”, *Electrical power quality and utilization journal*, Vol 14, No 1, 2008.
- [13] Apinan Aurasopon, “ Resonant DC link in PWM AC chopper”, *World Academy of Science, Engineering and Technology International Journal of Electrical, Computer, Energetic, Electronic and Communication Engineering* Vol:3, No:8, 2009.
- [14] A.N.Aravindan and J.Simon Alphonse, “Investigation of harmonic distortion in line and load currents of the sinusoidal pulse width modulated single phase AC chopper”, *IEEE conference*, 2014.
- [15] Cherl-Jin-Kim, Chul yong choi, Dal Eun Lee,Geun Soo Choi and Soo Hyun Baek ,” Torque characteristics of single phase induction motor for phase control method”, *IEEE conference*, 2004.
- [16] S.Williamson, D.Pearson and A.M.Rugege,” Acoustic noise and pulsating torques in a triac controlled permanant split capacitor fan motor,” *IEE proceedings*, vol 128, no 4, pp 201-206, July 1981.
- [17] Deniz Yildirim and Murat Bilgic ,” PWM AC chopper control of single phase induction motor for variable speed fan applications”, *IEEE conference*, 2008.

BIOGRAPHIES OF AUTHORS



N. Murali has 10 years of teaching experience. Now he is working as a Consultant. His current areas of research are Optimization techniques, power electronics and drives, electrical machines and power electronics application in power system. He has published 6 research papers in international journals and 6 papers in national conferences. He is a Life member of System society of India.



Prof. Dr. V. Balaji has 16 years of teaching experience. Now he is working as a Associate Professor in the school of Electrical and Computer Engineering, Bahir Dar University Ethiopia. His current areas of research are model predictive control, process control, image processing Fuzzy and Neural Networks. He has received Dr.APJ Abdul Kalam Award for Young Scientist, Excellence in Education Award, Best Teacher Award, World's Greatest person Award He has published 60 research papers in national and international journals conferences and two textbooks in the field of electrical engineering. www.vbalaji.com website was created by him and the study materials were uploaded. He is guiding eight research scholars in various universities. He is an active member of ISTE, IAENG, IAOE, IACSIT, FMIAEME, LMIAOE, LM IACSIT, SMIRE, MIIRJC. He is also serving as an Chief Editor, editorial board member and reviewer in the reputed national and international journals and conferences