Performance Analysis of TRIAC and MPWM of AC Voltage Controller Fed Capacitor Run Induction Motor

N.Murali, S.Gobi Mohan

Abstract**: *Single phase capacitor run induction motor is necessary to operate meritoriously and enhance the power quality. AC voltage controller is utilized effectively for controlling the speed of the motor. It employs conventional TRIAC and sinusoidal pulse width modulation control. The performance parameters are total harmonic distortion, input power factor and efficiency are the main concern. The comparative analysis of the two methods was simulated using MATLAB Simulink platform. Speed control of capacitor run induction motor used in domestic and industrial applications.***

Keywords **: *Harmonics, power factor, duty cycle, pulse width modulation and filters***

I. INTRODUCTION

Single phase capacitor run induction is employed for domestic load applications. The main reason is due to low cost and speed control is achieved by simpler circuits. The conventional speed control method uses mechanical devices and variable resistance control. The major drawback of these conventional techniques is wastage of power, size of controller is bulkier and maintenance cost is high [1]. In order to replace the conventional controllers the power electronic controllers are employed. The basic control techniques are integral cycle control and phase angle control. These control techniques are effectively used in industrial heating and lighting control. The integral cycle control has inherent advantage of zero current switching but it has drawback of harmonics in the output voltage [2]. In the next type, the output is varied by different firing instants by the phase angle control. The main advantage is by electronically the output voltage is controlled by varying the firing instants. The major drawback is harmonics in the output voltage is more for higher triggering angle and harmonics in the output voltage is more [3].

In the literature the single pulse width modulation is applied for speed control of induction motors. It is inferred that compared to phase angle control the single pulse width modulation is inferior [4]. The energy saving capability is slightly higher for phase control compared to single pulse width modulation technique [5]. It is understood that multiple pulse width modulation has better performance compared to phase control. The harmonics in the output voltage will be minimum, smooth input voltage and improved power factor [6]. In the literature the pulse width modulation is applied for resistive and inductive load similar to induction motor. In this paper the performance parameters are total harmonic distortion of current and voltage, input power factor and efficiency. These parameters are compared between two methods of speed control techniques. The control techniques are phase angle control using TRIAC control and multiple pulse width modulation technique using sinusoidal signal as the reference [7].

The paper is systematized in the following manner, the section 2 designates the basic operation of single phase capacitor run induction motor. The section 3 is designated for the basic operation of TRIAC control of capacitor run induction motor and working of multiple pulse width modulation technique and in the section 4 is designated for the performance characteristics of the two techniques. The results are compared and discussed.

II. WORKING OF CAPACITOR RUN INDUCTION MOTOR

The analysis of single phase capacitor run induction motor is done by two field revolving theory. The purpose of capacitor in the motor is to improve the power factor and revolving field used as starting conditions. The equivalent circuit of capacitor run induction motor is given below [8].

In the equivalent circuit the V is called as the supply voltage. Xc is the capacitive reactance which is connected in the auxiliary winding. Ra, Xa are the resistance and reactance of the auxiliary winding. Rm, Xm are the resistance and reactance of the main winding. Rf, Xf are the forward equivalent resistance and reactance. Rb , Xb are the backward equivalent resistance and reactance. Efm, Ebm are the self-induced forward and backward emf while a Ef and aEb are the mutually induced emf. The application used in the paper is domestic fans which need to be controlled in efficient manner. The torque is obtained for the fan load is [9].

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* Correspondence Author
Dr.N.Murali*, Electrical Engineering department, Nizwa College of Technology, Nizwa, Oman. Email: murali.narayanamurthy@nct.edu.om
Mr.Gobi Mohan, Electrical Engineering department, Nizwa College of Technology, Nizwa, Oman. Email: gobi.sivasubramanian@nct.edu.om

$$T = K * \omega^2 \qquad (1)$$

Where T is the torque, K is the proportionally constant and ω is the angular speed in radians per second.

For one horse power motor with 4 pole machine, the torque is obtained by

$$T = \frac{746}{157} = 4.75\ N - m \qquad (2)$$

From this equation the value of K is attained as

$$K = \frac{T}{\omega^2} \qquad (3)$$

$$K = \frac{4.75}{(157)^2} = 1.92 X 10^{-4} \qquad (4)$$

The attained value of K is utilized in the simulation for the fan load.

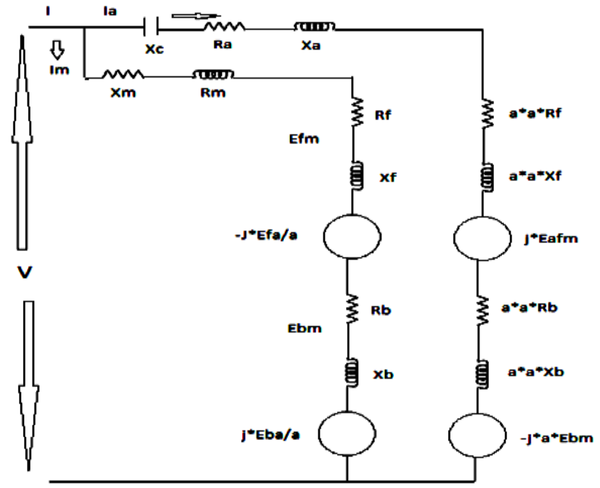

Fig. 1.Equivalent circuit of capacitor run induction motor.

III. CONTROL STRATEGIES OF CAPACITOR RUN INDUCTION MOTOR

The power electronic device is connected at the supply end and to the main winding of the single phase capacitor run induction motor. In the simulation the TRIAC is not available hence the construction has been made by using two thyristors in anti-parallel. During the positive half cycle the terminal MT1 is positive and current flows through the motor and back to the supply. During negative half cycle the current flows through motor and the terminal MT2 and returns back to the supply. The TRIAC can operate only in two quadrants, the other two quadrants are unstable in nature.

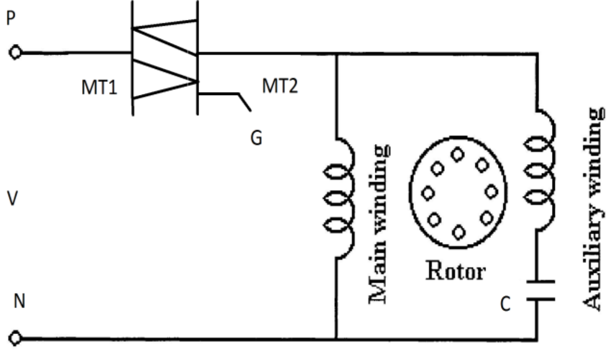

Fig. 2.TRIAC control of capacitor run induction motor.

The improved control strategy is multiple pulse width modulation technique using sinusoidal pulse width modulation. It consists of one IGBT device with four diodes as a main switch and another set of one IGBT and four diodes for the freewheeling action is shown in figure 3. The switch S1 operates in both the directions of the input supply. The pulse generation for switch S1 will be opposite to the switch S2. The sinusoidal pulse width modulation technique is used for generating the triggering signals.

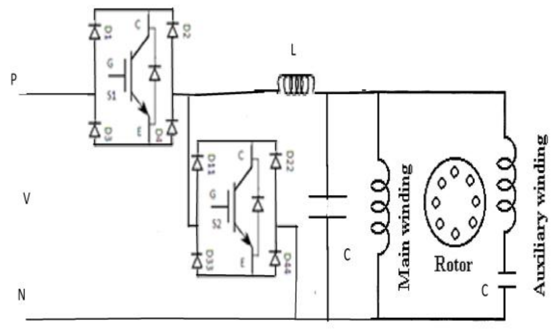

Fig. 3.MPWM control of capacitor run induction motor.

IV. DESIGN OF FILTER CIRCUIT PARAMETERS FOR MPWM

The design of filter is required for the multiple pulse width modulation is required to remove the higher order frequency components [11][12]. The design of passive filters is the utmost importance for getting a smooth output waveform. The inductance value is obtained from the below equation [14]

$$L = \frac{\sqrt{2(R_o{}^2 + X_o{}^2)}}{D * \pi * \omega_s * THD_i} \qquad (5)$$

Where Ro is the load resistance, Xo is the load reactance, D is the duty cycle, THDi is the total harmonic distortion of current and ωs is the angular frequency in radians per second. The total impedance is obtained by open circuiting the auxiliary winding is as follows

$$Z = R_m + R_{miron} + \frac{R_r}{4} + \frac{jX_{mm} + X_r}{2} + jX_m \qquad (6)$$

where R_{miron} is given by iron losses / $(Imo)^2$ and Imo is no load main winding current. The value of capacitance is given as follows

$$C = \frac{\sqrt{2} * V * (1 - D)}{8 * L * \Delta V * f_s{}^2} \qquad (7)$$

where ΔV is the ripple voltage which is taken as 1% and fs is the switching frequency operating at 20 kHz. The power factor angle θ is given below

$$\theta = \tan^{-1}\left(\frac{D * I_o * \sin\phi - \omega * C * V}{D * I_o * \cos\phi}\right) \qquad (8)$$

where Io is the load current, ω is the angular frequency in radians per second, V is the main winding voltage and ϕ is load angle and the formula for ϕ is given as

$$\phi = \tan^{-1}\left(\frac{\omega * L_o}{R_o}\right)$$

(9)

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From the above equation the power factor is calculated by
Power factor = cos ϕ
From this design the inductance and capacitance values are obtained as follows L =0.25 milli henry and C = 70 micro farad.

V. RESULTS AND DISCUSSION

The performance parameters are total harmonic distortion of input current, input power factor and efficiency. The voltage and current waveforms are shown in figure for the both types of controllers. It is inferred that when the triggering angle is more than 80 degrees the output waveforms are not smooth. In multiple pulse width modulation the output waveforms without filter has higher order frequency components. When filter is included in the circuit the higher order frequencies are removed and the waveform is better compared to triac controllers.

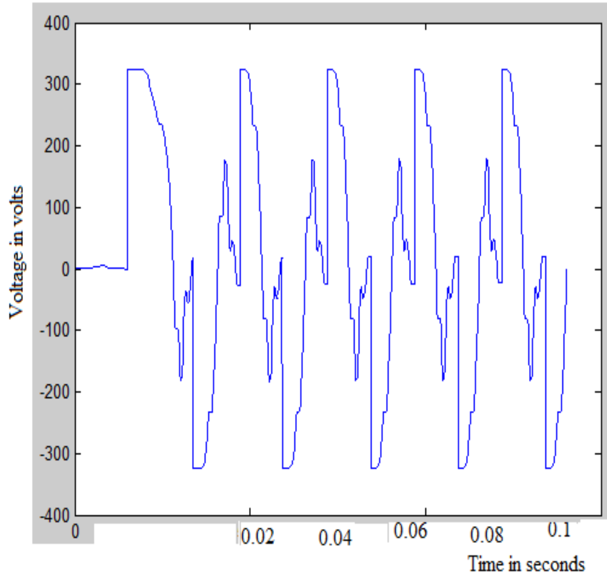


Fig. 4.Voltage waveform of TRIAC controller at 90 degrees.

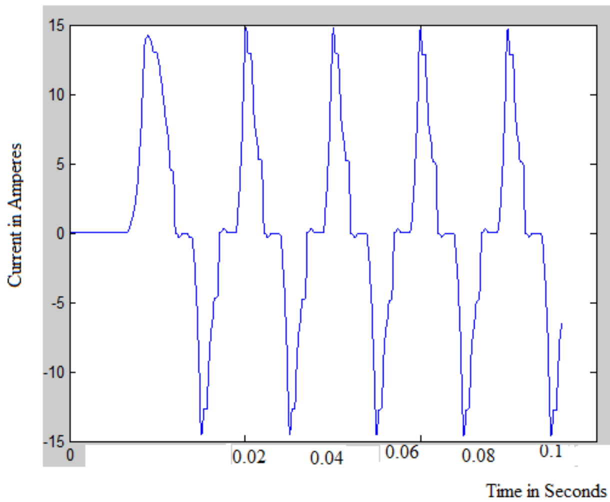
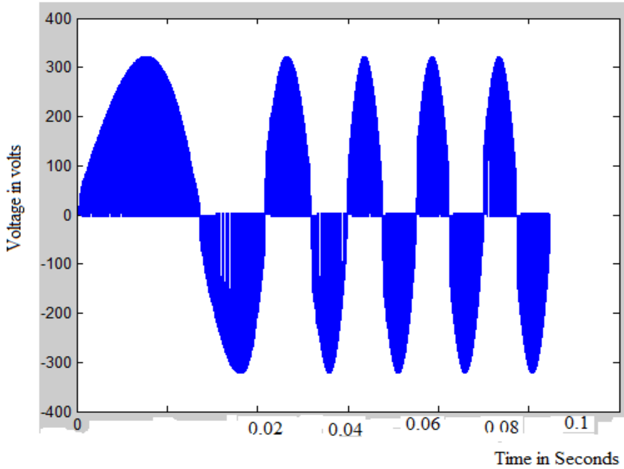
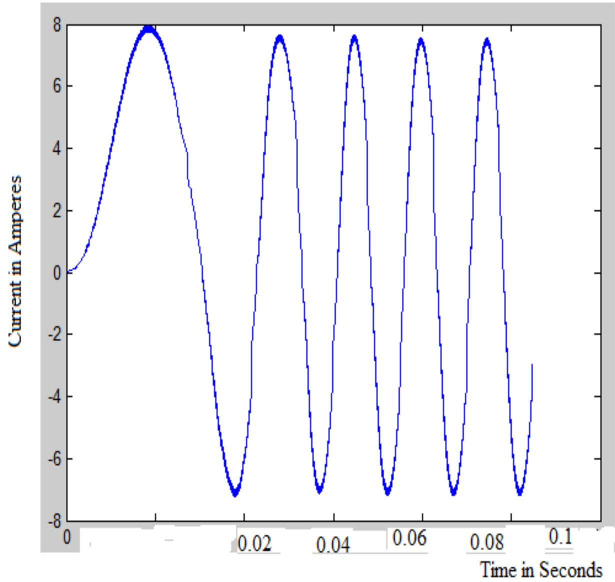


Fig. 5.Current waveform of TRIAC controller at 90 degrees.



Voltage waveform of MPWM controller without filter at 0.5 duty cycle.



Voltage waveform of MPWM controller without filter at 0.5 duty cycle.

The total harmonic distortion is simulated for both the type of controllers. It is inferred that TRIAC control has higher harmonic distortion which leads to unsuitable for industrial applications. The level of harmonic distortion is high and usage of passive filters also lead to unstable operation. In multiple pulse width modulation technique the harmonic level is less compared to TRIAC control. The percentage of harmonic distortion is high compared to IEEE standards of 5%. This can be enhanced by suitable methods of selective harmonic elimination techniques for lesser harmonic distortions. In multiple pulse width modulation the current total harmonic distortion is above the IEEE standards and it can be improved by asymmetrical pulse width modulation technique.

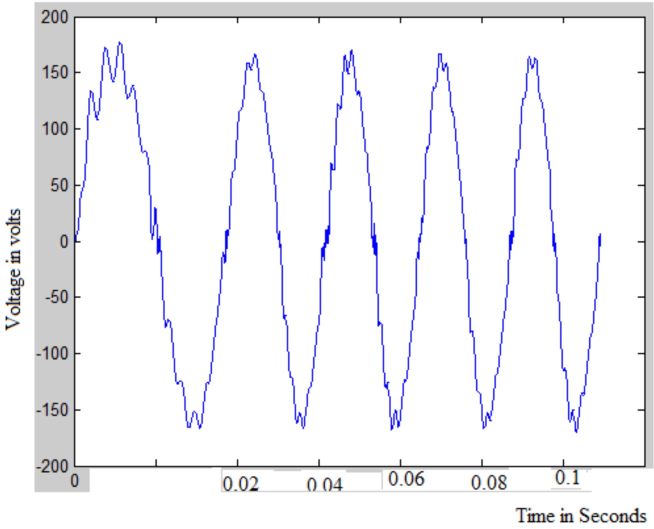


Fig. 6.Voltage waveform of MPWM controller with filter at 0.5 duty cycle

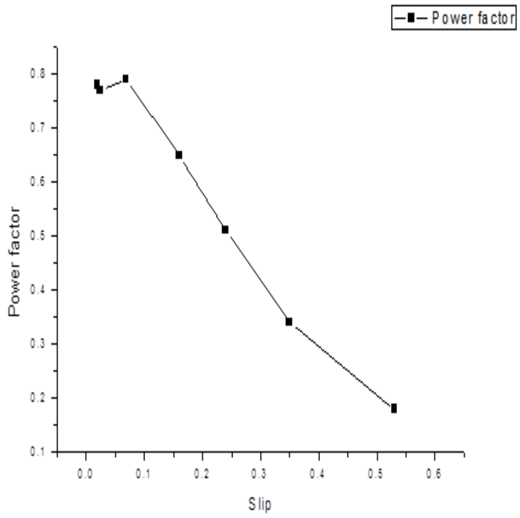


Fig. 8.% slip versus power factor of TRIAC controller

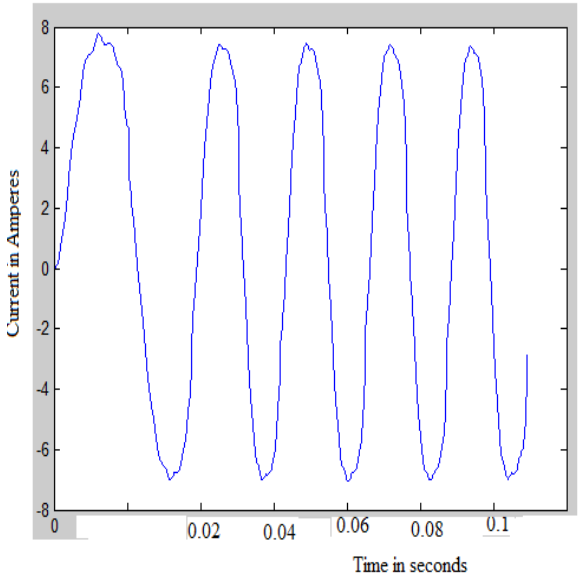


Fig. 7.Current waveform of MPWM controller with filter at 0.5 duty cycle

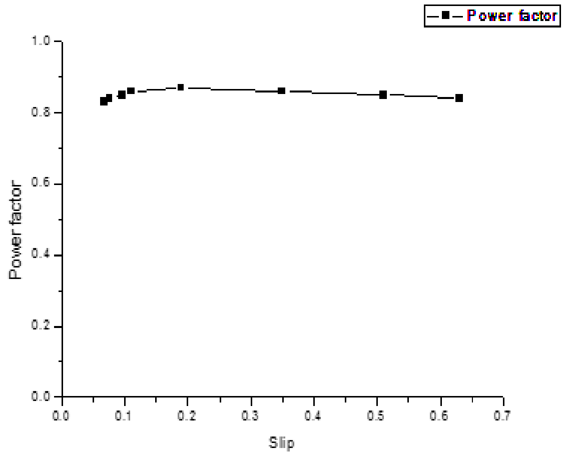


Fig. 9.% slip versus power factor of MPWM controller

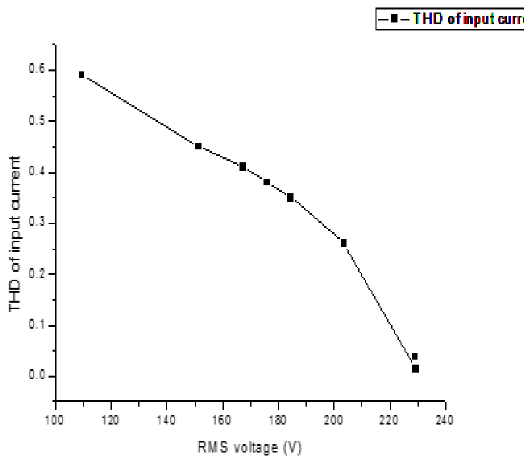


Fig. 10. % THD input current versus RMS voltage of TRIAC controller

The performance parameter input power factor is compared between conventional and proposed controller. The graph shown in figure 10 and 11 infers that at higher values of % slip the power factor decreases in TRIAC controller. Hence the power factor is poor while operating at lower speeds. The multiple pulse width modulation control has good power factor at all slip speed. Hence this converter is suitable for any load conditions. The torque slip characteristics shown in figure 14 and 15 infers that multiple pulse width modulation technique has better control compared to TRIAC control for different loading conditions. It is inferred that harmonics present in the multiple pulse width modulation technique is more due to the presence of third harmonic component. This lower order harmonics cannot be filtered using passive filters. This harmonics need to eliminated by using the selective harmonic elimination technique.

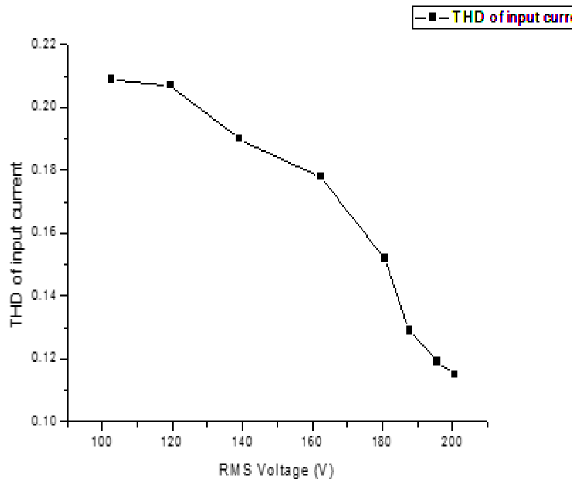


Fig. 11. % THD input current versus RMS voltage of MPWM controller

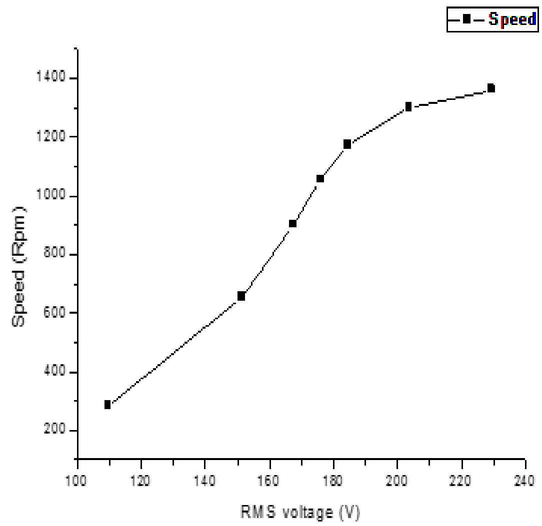


Fig. 14. Speed versus RMS voltage of TRIAC controller

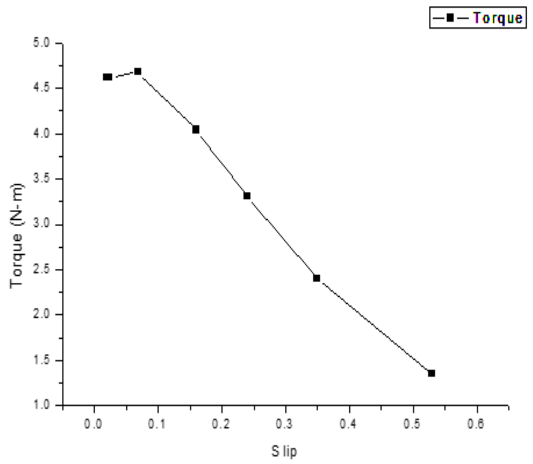


Fig. 12. Torque slip characteristics of TRIAC controller

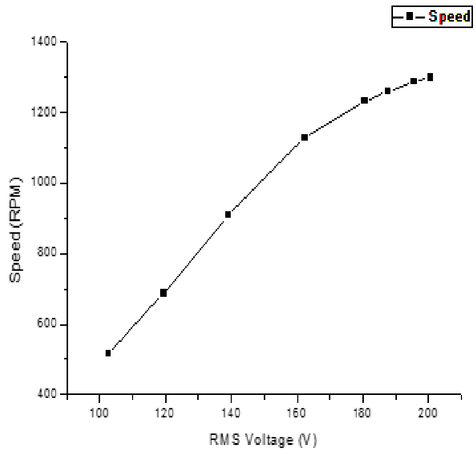


Fig. 15. Speed versus RMS voltage of MPWM controller

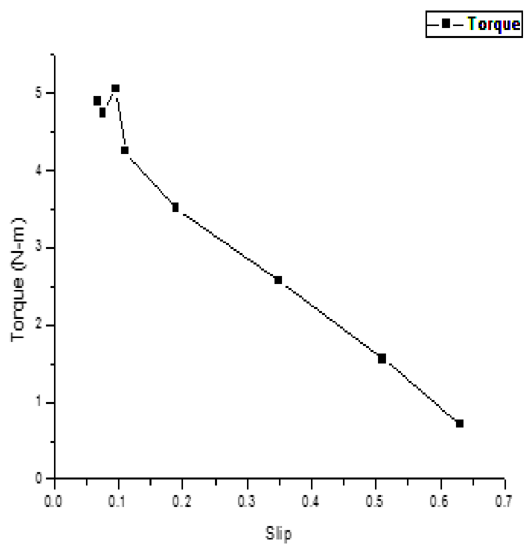


Fig. 13. Torque slip characteristics of MPWM controller

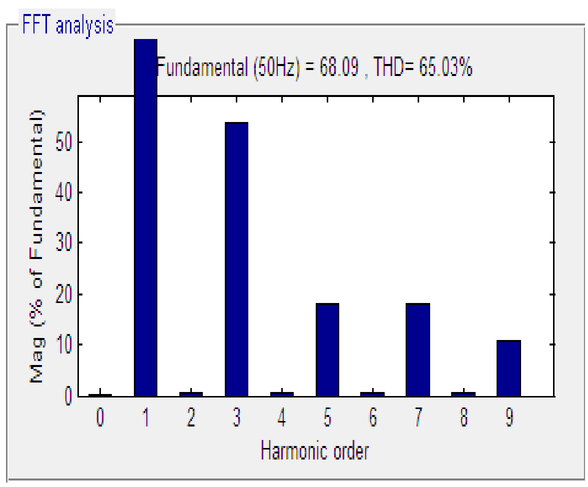


Fig. 16. Harmonic spectrum of TRIAC controller

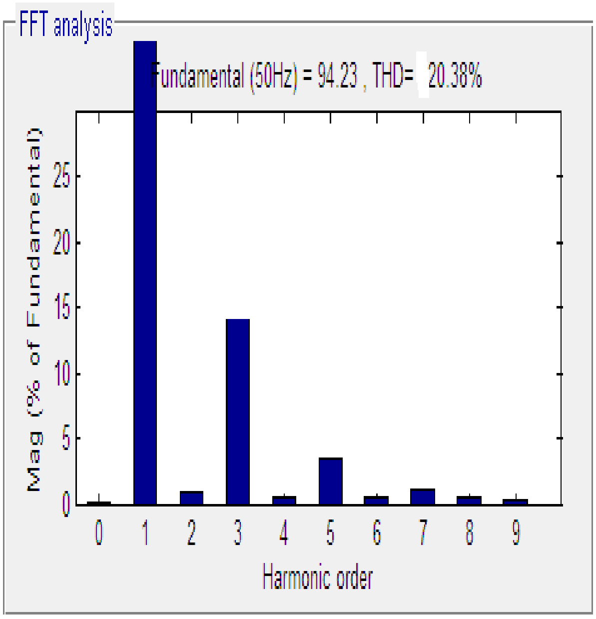


Fig. 17. Harmonic spectrum of MPWM controller

VI. CONCLUSION

The improved performance parameters have been incorporated in the multiple pulse width modulation technique. The shortfall of poor smoothness in the waveform, poor input power factor and nominal efficiency is exhibited in the TRIAC controlled capacitor run induction motor. The performance quality is improved in the multiple pulse width modulation technique. The waveform is near sinusoidal and power factor is improved and operating at near to the unity. The efficiency of the system has slight improvement compared to the existing system. The output voltage waveform has third harmonic component which need to be removed from the output. This can be further improved by utilizing the asymmetrical pulse width modulation technique.

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AUTHORS PROFILE

Dr.N.Murali has 17 years of teaching experience. He is working as a Lecturer in the Department of Electrical Engineering, Nizwa College of Technology, Oman. His current areas of research are Optimization techniques, power electronics and drives, electrical machines design using Ansys, power electronics application in power system, IOT based renewable energy systems and power electronics application in renewable energy systems. He has published 10 research papers in international journals and 10 papers in national conferences. He is a Life member of System society of India.

Gobimohan Sivasubramanian, is an Indian, Lecturer, Department of Electrical Engineering, Nizwa college of Technology, Oman.He was born in 1975 in Tiruchirappalli, Tamilnadu, India. He received the B.E. degree from Bharathidasan University (1996) and M. E., degree from MIT campus, Anna University in 2000. He has around 24 years of teaching experience . His area of interest includes Renewable energy, Power Electronics , Soft Computing Techniques. He has the ability to look on the better side of life instead of focusing on problems. He has published 4 research papers in international journals and 3 papers in national conferences. He is a Life member Indian society for Technical education.