INVERTER POWER CONTROL BASED ON DC-LINK VOLTAGE REGULATION FOR IPMSM DRIVES USING ANN

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Abstract - *This paper proposed an inverter power control strategy based on DC-link voltage regulation using electrolytic capacitor for Interior Permanent Magnet Synchronous Motor (IPMSM) drive system. The DC-link electrolytic capacitor is used for the voltage regulation. The inverter power should be regulated effectively to achieve high input power factor and low grid current harmonics. Artificial Neural Network (ANN) is used for better operation and to reduce the torque ripple which is required for better performance of motor. The PI controller can be design to achieve a high gain at the desired frequency and the parameters are easy to design due to the simple structure. In addition, a power compensation method based on the DC-link voltage regulation is used to diminish the error of inverter power control. The effectiveness of the proposed method was simulated and the torque ripple was reduced with low Total Harmonic Distortion (THD). The input power factor can reach 0.98 and the harmonics of grid current was reduced.*

Keywords: Interior Permanent Magnet Synchronous Motor (IPMSM), electrolytic capacitor, voltage regulation, Artificial Neural Network (ANN) PI controller

1. INTRODUCTION

In recent years, Interior Permanent Magnet Synchronous Motors (IPMSMs) have been widely used in industrial applications and home appliances. Large volume electrolytic capacitors are usually utilized at the DC-link of IPMSM drive to buffer and store energy, which can stabilize the DC-link voltage and supply power for the inverter.

The Power Factor Correction (PFC) circuit is necessary to improve the power factor and reduce the Total Harmonic Distortion (THD) of the input current in fractional horsepower motor drives. Because of the elimination of the PFC circuit, the efficiency and reliability of the drive system can be improved. The method based on the predictive control and the instantaneous power theory was proposed to shape the grid current and increase the power factor.

The cost of the system can also be reduced, which is an important concern in industry applications. The table1.1 shows the harmonic standards of EN61000-3-2. By reducing the THD, the system performance will increase. In this paper a proposed system was introduced. The Electrolytic capacitor is used with ANN (Artificial Neural Network), for better operation.

The inverter power control strategy is used for voltage regulation. The Three phase inverter regulated the input current waveform using an additional current controller. This proposed method could improve the power factor. In order to reduce the THD, the sinusoidal d and q axis current generation was replaced by an approximately trapezoidal waveform generation.

In this paper, a novel inverter power control algorithm is proposed including an inverter power control loop with a controller and a power compensation method based on DC-link voltage regulation, in order to achieve high input power factor and low grid current harmonics. The inverter power control loop with another PI controller is aimed at regulating the inverter power to be sinusoidal. An improved power compensation method based on the DC-link voltage regulation is applied to enhance the inverter power control performance.

Using of ANN, the torque ripple was reduced; torque is the important parameter for a motor to do its performance .The total cost of the system become low by using the specific components. The distorted inverter power can be detected by the DC- link voltage regulation.

Harmonics [n]	Class A [A]	Class B [A]	Class C [% of fund]	Class D [mA/W]
		Odd harmonics		
3	2.30	3.45	30 x λ	3.4
5	1.14	1.71	10	1.9
7	0.77	1.155	7	1.0
9	0.40	0.60	5	0.5
11	0.33	0.495	3	0.35
13	0.21	0.315	3	3.85/13
15 ≤n ≤39	0.15 x 15/n	0.225 X 15/n	3	3.85/n
		Even harmonics		
2	1.08	1.62	2	-
4	0.43	0.645	-	-
6	0.30	0.45	-	-
8 ≤n ≤40	0.23 x 8/n	0.345 x 8/n	-	-

Table 1. Harmonic Standards of EN61000-3-2

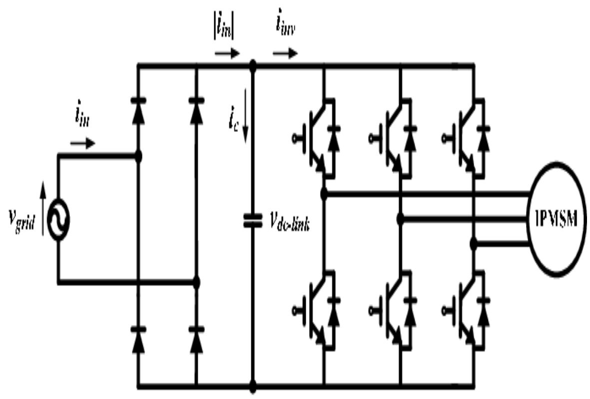

Figure 1. Circuit Diagram of Electrolytic capacitor with IPMSM drive system

The figure 1 shows the simple circuit diagram of electrolytic capacitor with Interior Permanent Magnet Synchronous Motor drive system (IPMSM). The Diagram has the AC input with DC link voltage capacitor and the inverter side switches connected to IPMSM drive system. In the proposed system, ANN with PI controller will connect to get the outputs.

2. LITERATURE REVIEW

Alemi et al. [1] proposed a novel control algorithm that minimizes the dc-link capacitance in the T-type three-level back-to-back converter is proposed. The effectiveness of their proposed strategy has been verified by the simulation and experiment results for a 3-kW T-type three-level ac/dc/ac pulse width modulation converter system with a 50- μF film capacitor in the dc-link. Kang et al. [2] proposed a control strategy for high power factor without electrolytic capacitor in home appliance. The proposed system consists of single-phase diode rectifier, small film capacitor (20uF), three-phase voltage inverter and AC motor. In order to obtain a high power factor, this paper proposes a new control method that delays q-axis current compared with phase of grid voltage.

Lee et al. [3] proposed a novel control scheme of single-phase-to-three-phase Pulse Width-Modulation (PWM) converters for low-power three-phase induction motor drives, where a single-phase half-bridge PWM rectifier and a two-leg inverter are used. The experimental results for the V/f control of 3-hp induction motor drives controlled by a digital signal processor TMS320C31 chip have verified the effectiveness of the proposed scheme.

Inazuma et al. [4] proposed a new power factor correction method using an inverter-driven Interior Permanent Magnet (IPM) motor. The proposed system realizes the high power factor of a single-phase diode rectifier by using a three-phase pulse width modulation inverter and an IPM motor. The maximum power factor obtained by the proposed method is 98.7% at the rated-load conditions. The superior performance of the proposed system is demonstrated by experimental results.

A motor drive system fed by a single-phase diode rectifier without Power Factor Correction (PFC) circuit or the input filter was described in [5]. Proposed method, the harmonic components of the grid input current can be reduced under the limits of the regulation IEC61000-3-2, lower than those in the conventional method. The performance of the proposed shaping method was validated by the experimental results using the motor drive system with a 5μF film capacitor at dc link. In the field weakening the voltage is utilized to the maximum to minimize the current amplitude was discussed in [6]. In this paper, the hexagonal voltage limit is considered to increase the voltage and to decrease the current, as a result to reduce the copper loss. In the simulation and experiment results, an increase of voltage and a decrease of current were observed. In addition, an improvement of the motor and inverter efficiencies was also achieved.

Lam et al. [7] explained about light emitting diode (LED) lamps with ac-input (50 or 60 Hz) usually require an electrolytic capacitor as the dc-link capacitor in the driver circuit to: 1) balance the energy between the input and output power, and 2) to minimize the low-frequency component of the output ripple across the LEDs. Simulation and experimental results are given on a 9-W LED lamp to highlight the merits of the proposed circuit. Lamsahelet al. [8] proposed a control strategy for drives in home appliances with small energy storage in DC-link. The method is based on the field-oriented control and uses the modulation of the d-q-axis currents of the PM. Simulations and experimental results in this paper demonstrate the feasibility of this method.

Nannan Zhao et al. [9] proposed a DC-link electrolytic capacitor critically affects the lifetime of the motor drive system. This paper proposes an inverter power control strategy based on DC-link voltage regulation for the electrolytic capacitor-less Interior Permanent Magnet synchronous motor (IPMSM) drive system. The effectiveness of the proposed method is demonstrated by the experimental results on an air conditioner. The input power factor can reach 0.992 and the harmonics of grid current are considerably lower than the requirement of EN61000-3-2 standard.

3. PROPOSED METHOD

The Proposed method deals with ANN and PI Controller. The Electrolytic Capacitor is replaced instead of Film Capacitor. The Proposed method is describes in the following pages.

3.1 Artificial Neural Network (ANN):

ANN: A computing system made up of a number of simple, highly interconnected processing elements, which process information by their dynamic state response to external inputs. The figure 2 shows the different layers of ANN [10].

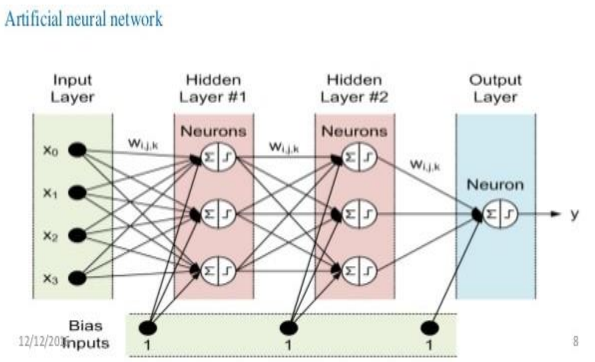

Figure 2. Layers of ANN

Incoming data is then sent to the next layer. The next layer is a hidden layer. This layer contains neurons that can receive data or electrical signal than the previous layer of the input layer. Data or electrical signal that goes into these layers is processed using the functions available such as arithmetic, mathematics, etc. The hidden layer can contain one or more neurons, which depends on the suitability and complexity of the case at hand. Data processing results of this layer is then routed to the output layer. Output layer plays a role in deter mining the validity of data that are analyzed based on the existing limits in the activation function. In the Proposed method, ANN is used for better operation and the torque ripple is also reduced.ANN compares the waveforms, it reduces the error and it gives the better output for the system.

3.2 Proportional Integral (PI):

P-I controller is mainly used to eliminate the steady state error resulting from P controller. However, in terms of the speed of the response and overall stability of the system, it has a negative impact. Integral control eliminates the steady state error. After certain limit, increasing K¬i will only increase overshoot. Increasing K¬i reduce the rise time a little. The Figure 3 shows the block of PI Controller.

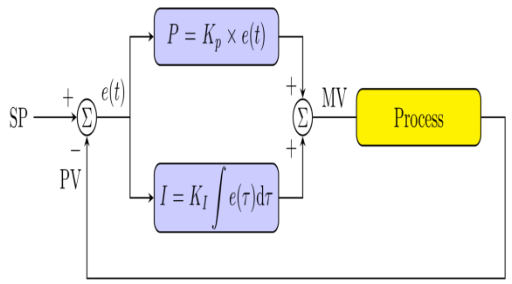

Figure 3. Block of PI controller

3.3 ELECTROLYTIC CAPACITOR (EC):

An electrolytic Capacitor is a polarized capacitor whose anode or positive plate is made of a metal that forms an insulating oxide layer through anodization. This oxide layer acts as the dielectric of the capacitor. A solid, liquid, or gel electrolyte covers the surface of this oxide layer, serving as the (cathode) or negative plate of the capacitor. The Figure 4 shows the Different sizes of Electrolytic Capacitors [12, 14]. In the proposed method, Electrolytic Capacitor is used instead of film capacitor. The Electrolytic Capacitor is used to get the high power factor.

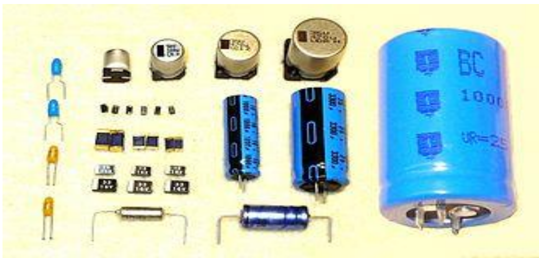

Figure 4. Different Sizes of Electrolytic Capacitors

3.4 Interior Permanent Magnet Synchronous Motor (IPMSM):

IPMSM is better than Induction Motor. A permanent magnet motor's full load efficiency is higher than an AC induction motor .They may offer a smaller size for more compact mechanical packages and, more importantly, higher efficiencies.

The advantages of permanent magnet motors include higher efficiencies smaller sizes permanent magnet motors can be as much as one third of most AC motor sizes, which makes installation and maintenance much easier, and PMSMs' ability to maintain full torque at low speeds.

The figure 5 shows the different between IPMSM and IM. Because of the many advantages of the interior permanent magnet synchronous motor (IPMSM) over the induction motor, it has been used in many industrial applications as well as office and home equipment. Besides high efficiency, extensive constant power operating range is also desired in many applications.

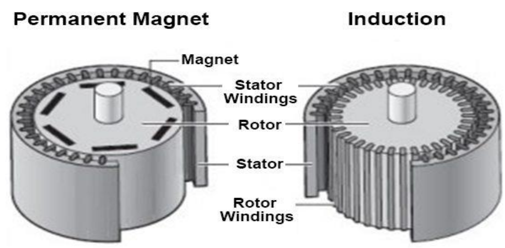

Figure 5. PMSM VS IM

FEM analysis in the experiments show that the permanent magnet armature flux linkage can be effectively adjusted by controlling the gap length between iron plates and the rotor. It is verified that the operating range of the proposed IPMSM can be greatly extended by lowering the PM armature flux level above base speed using the iron plates. The Table 2 shows the simulation parameters of IPMSM.

In the Proposed method, IPMSM is used for higher efficiency of the motor. IPMSM has more advantages than Induction Motor.

PMSM Motor Specifications			
Parameter	*Value*	*Parameter*	*Value*
Rated torque	28 Nm	Rated speed	3700 rpm
Rated current	25 A	Rated voltage	400 V
PMSM Motor Parameter			
Parameter	*Value*		
Stator resistance (R_s)	0.165 Ω		
Core loss resistance (R_c)	516.03 Ω		
Direct-axis inductance (L_d)	4.48 mH		
Quadrature-axis inductance (L_q)	7.98 mH		
Permanent magnet flux linkage (λ_m)	0.1121 V·s		
Number of pole pairs (n_p)	5		

Table 2. Simulation parameters of IPMSM

3.5 Bridgeless Interleaved Converter (BIC):

This topology employs a bridgeless converter for active power factor correction. The prime feature of this topology is that the need for input diode bridge rectifier stage is eliminated completely, while still maintaining the classic boost topology. In effect, the bridgeless IBC topology combines the benefits of both the bridgeless topology and the interleaved structure [11]. The Figure 6 shows the circuit diagram of Bridgeless Interleaved Converter.

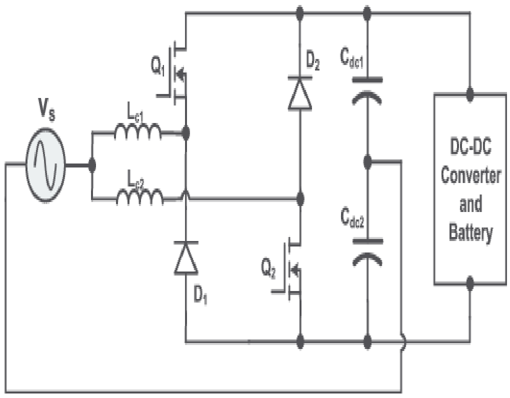

Figure 6. Circuit Diagram of Bridgeless Interleaved Converter.

In the Bridgeless Interleaved Converter topology, the rectifier stage is integrated with the high frequency converter. Due to the elimination of the bridge rectifier stage, the circuit becomes less bulky. Interleaving leads to an increase in the frequency of input current ripples and hence a reduction in the weight and volume of EMI filters required.

3.6 INVERTER:

Three phase inverters are used for variable-frequency drive applications and for high power applications such as HVDC power transmission. The Figure shows the circuit diagram and waveforms of the three phase inverter. Inverter is used to convert the DC into AC. It gives the supply to the motor operation as AC. Space Vector Pulse Width Modulation inverter is used in the proposed work.

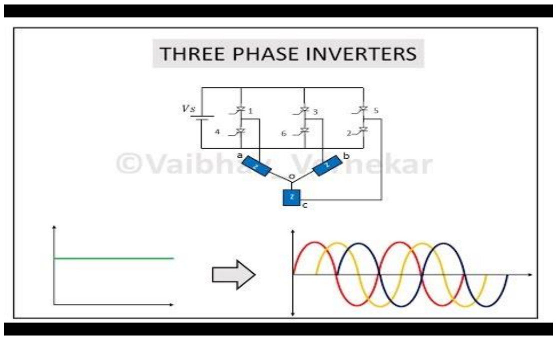

Figure 7 Simple Circuit of Inverter

3.7 FIRING CIRCUIT:

Triggering or firing is one of the key issues associated with SCRs or Thyristors. The performance of the circuit and the very way it operates will be largely dependent upon the SCR triggering or firing method chosen. The Figure 8 shows the circuit diagram of Firing Circuit. The Triggering circuit is called Firing circuit.

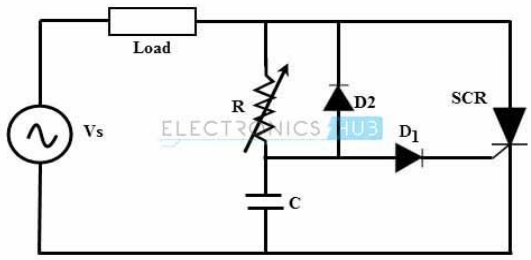

Figure 8 Firing Circuit

3.8 BLOCK DIAGRAM OF THE PROPOSED METHOD:

The Block Diagram of the proposed method was given in the figure 9. The proposed system has ANN (Artificial Neural Network) for the better operation. The circuit has AC source which is given as supply to the circuit initially. The circuit has Bridgeless Interleaved Converter (BIC) which changes the AC supply into DC supply.

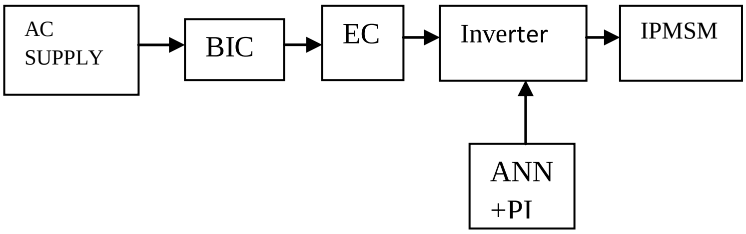

Figure 9 Block diagram of the Electrolytic capacitor for IPMSM drive system

The Electrolytic capacitor is used in the proposed system for the voltage Regulation. In the proposed system, it has ANN controller for better operation. The firing circuit also connected in the circuit for controlling operation.

4. RESULTS AND DISCUSSION

MATLAB supports developing applications with graphical user interface (GUI) features. The Figure 10 describes about the Simulation result of the proposed work.

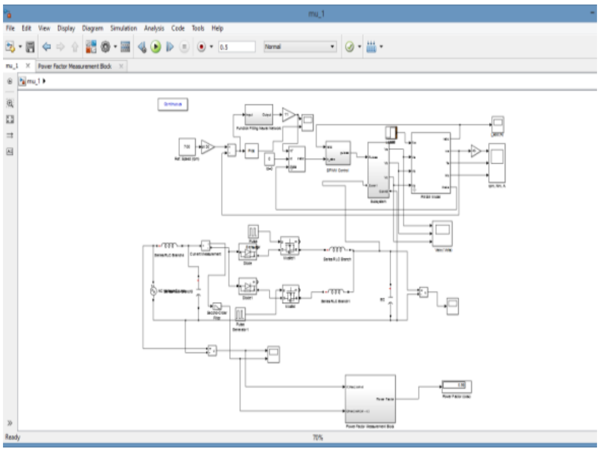

Figure: 10 Simulation of the Proposed Work

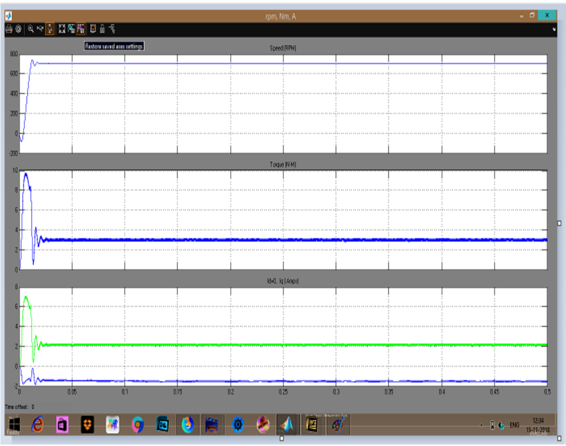

Figure 11 Output waveforms of Speed and Torque

The figure 11 is the output waveforms of the simulation for the proposed work. The Torque ripple was reduced for the given speed .The speed was given as 700rpm.The Torque is the main parameter for a motor for its performance. So the torque ripple was reduced.

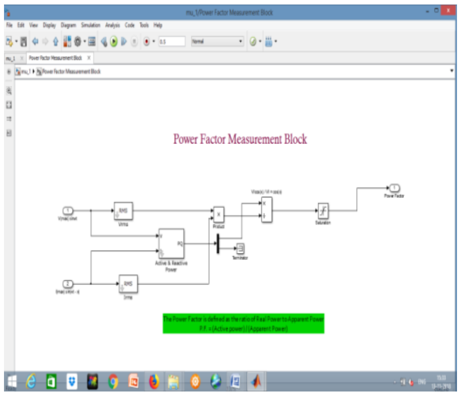

Figure 12 Power Factor measurement block

The figure 12 shows the power factor measurement block. In fact, KVAR approaches zero, your power factor approaches 1.0.In the simulation output, the power factor was reached as 0.98.

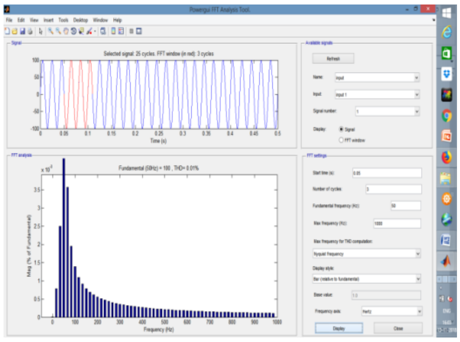

Figure: 13 Total Harmonic Distortion of Proposed Work

The figure 13 shows the Total Harmonic Distortion (THD) of the proposed work. The Distortion in the output was reduced. It can be measured for the each cycle. The frequency was set as 100Hz.The THD was measured in the Fast Fourier Transform (FFT) window

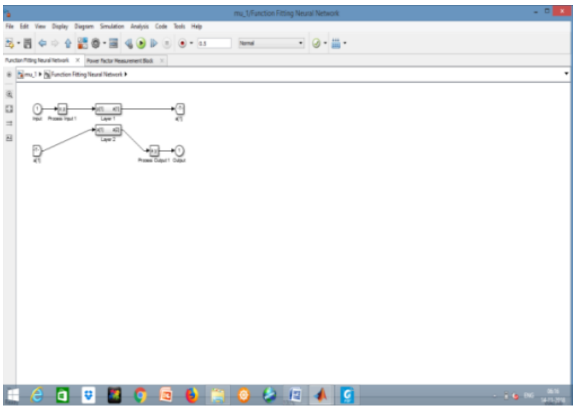

Figure: 14 ANN Block

The Figure 14 shows the working of ANN. It compares the input and it process in the circuit and gives the output without error.ANN has three layers such as Input, Hidden and Output layers.

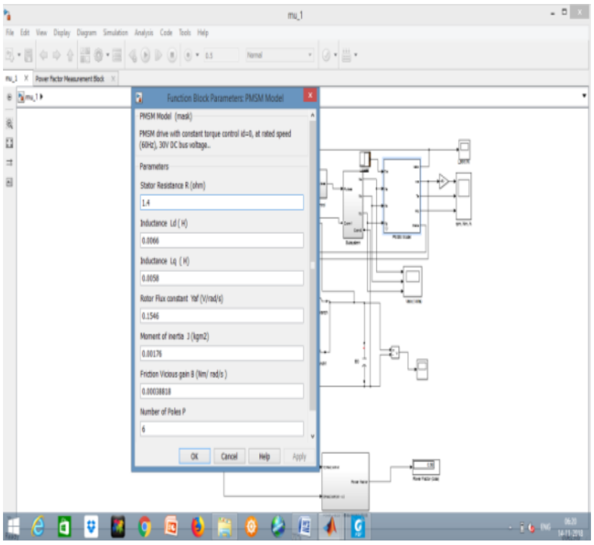

Figure 15 Simulation parameters of IPMSM

The figure 15 is the simulation parameters of the IPMSM. The simulation parameters for the motor were set up. The figure 16 shows the waveforms of the voltage and current with time in the x-axis. These waveforms are the given as input for Power Factor measurement block and for the Bridgeless Interleaved Converter.

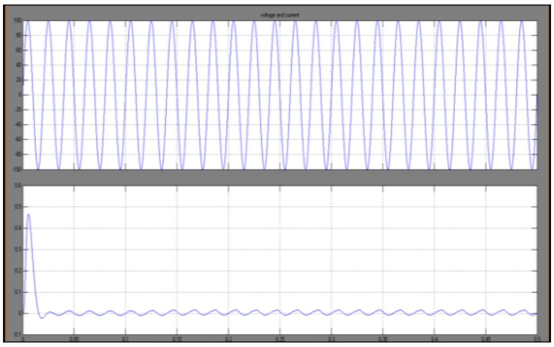

Figure: 16 Voltage and Current waveforms

5. CONCLUSION AND FUTURE SCOPE

The proposed method was described with an Electrolytic capacitor with ANN and PI for the better operation and performances. ANN and PI reduce the errors in the output and the Torque ripples were reduced. The power factor also reached as0.98.In real time, the cost of Electrolytic capacitor is low compared to film capacitor and it is available in small sizes. The Algorithm of ANN can be easily used and easily accessible. The Harmonics in the system was also reduced by an Electrolytic Capacitor. In the Future, this project is enhanced with replacement of ANN with Fuzzy Logic Circuit or Neuro fuzzy or QPSO (Quantum behaved Particle Swarm Optimization).The Algorithms can be use for better operation and to reduce the distortions in the waveforms. As the real time application, it is also experimented with Air Conditioning

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