Implementation of Improved Shunt Active Power Factor Correction Circuit for DTC Based PMSM

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Abstract**-** This paper describes the improvement of the power factor of the input power supply of the direct torque controlled inverter fed PMSM drive. By improving the power factor, the performance of PMSM can be improved. The proposed circuit includes the two parallel diode bridge rectifiers capable of providing good power factor which also maintains the simplicity. Normally, circuits with a bridge rectifier suffer from severe distortions in the phase angle of the input voltage and current, resulting in very low PF. By connecting two diode bridge rectifiers in parallel with series connected high-inductance on ac side, the harmonic distortion in current is reduced. Harmonics produced by one converters is opposed by other converter which is connected in parallel, hence these two harmonics cancelled by using harmonic injection based elimination technique. By proper turn-on of parallel-connected rectifier power switched to charge the inductor. When switched off, energy stored in the inductor is added to the ac power through the rectifier to mitigate the phase angle of the input voltage, so as to improve the PF. By improving the power factor of the ac supply with the proposed method, the performance of the DTC controlled PMSM can be improved with less distortions. Comparison of two different types of rectifiers with proposed shunt based rectifier has been simulated using Matlab/ Simulink which shows the enhanced performance of the proposed circuit and it has been proved with hardware implementation.

Keywords:- ***PMSM, Active Power Factor Correction, Direct Torque Control, Distortion.***

I. INTRODUCTION

In recent decades variable speed drives are becoming more popular especially Permanent Magnet Synchronous Motors (PMSM) due its special features like fast dynamic response, high power density, wide range of speed, high efficiency and reliability[1]-[3]. Permanent Magnet Synchronous Motors (PMSM) has an important role in motion control applications in the low and medium power range [4]. Direct torque control (DTC) is one of the controlling techniques which are used widely to control the torque and flux of the motors especially PMSM [5]. This control scheme requires DC supply which is achieved by conversion of AC mains voltage to DC using an AC-DC power converter. The resulting DC voltage is converted into variable frequency variable voltage AC by means of voltage source inverter (VSI) to operate PMSM

For this conversion process, if simple rectification with capacitor bank is used will produce narrow current pulse which results in poor power factor and power quality problems and affect active power[6]-[8]. In order to improve the active power, these power quality issues has to be considered while designing converter. The most of the motor control systems uses power factor improvement at the first stage to reduce the harmonic content and reactive power to improve the overall efficiency. There are two different types of power factor improvement: passive and active power factor correction (PFC). Low power factor linear load can be improved with a passive network (capacitors or inductors), reduces the harmonic current, which means that the non-linear device acts as a linear load [9]. A passive power factor correction requires large value high current inductors and capacitors to improve power factor and reduce total harmonic distortion of the input current. Passive filter are simple in circuit and low cost but can be used only for lower power range. At high power level, the size and weight of the passive components becomes problem [10]. On the other hand active power factor use active electronic circuits which consist of power electronic switches. This active power factor correction circuits uses small, light inductive components and they possess greater flexibility and control.

A novel power factor correction circuit with sensorless speed controller has been proposed for permanent magnet synchronous motor. The developed prototype comprises of two shunt rectifiers with satisfied power factor. The developed circuit accomplishes good power factor only when the motor speed exceeds 2800 rpm [11]. Dual stabilizing scalar V/F feedback correction control for PMSM has been proposed. The proposed topology uses voltage vector for speed correction and voltage amplitude correction for power factor regulation.

The experimental results validates better performance both in steady and transient states, whilst subjected to the load disturbance [12]. Active power filter with improved deadbeat control has been introduced to compensate the current harmonics in non linear load. The improved deadbeat control curb the undesirable effects of the current sampling error, boosts the interference rejection ability of the control system [13]. But the circuit is complex as compared to proposed paper. The input power factor compensation method has been proposed in [14] for PWM Current source converter fed PMSM drive. The proposed approach uses d-axis stator current component in field oriented control design of the drive. The feature of the proposed approach adjusts the line side power factor, without the existence of modulation index control for inverter and rectifier. The benefits of offline selective harmonics elimination control of modulation has been introduced in machine and line side to limit the harmonic distribution. Higher order harmonics can be easily eliminated by using filters, but the lower order harmonics only eliminated by PWM technique or harmonic injection technique[15]-[17].

In this proposed paper, a shunt-based, semi-active PFC circuit is used to improve the power factor of the input supply fed to inverter of PMSM drive which controlled by DTC method. The power switch connects a shunt circuit to the mains, such that low frequency signals can be used for the on and off the switch, thereby reducing the power losses associated with switching. Robust control strategy of shunt active power filters for PFC, harmonic compensation and balancing of non-linear loads are followed. The current controller has the task of making the controlled current tracking its respective reference. The two-quadrant active power filter, based on a conventional bidirectional DC–DC converter, connected to the output side of the diode bridge. Therefore, it has the benefit of lower switching loss and designed at higher switching frequency to reduce the current ripple and the size of passive components.

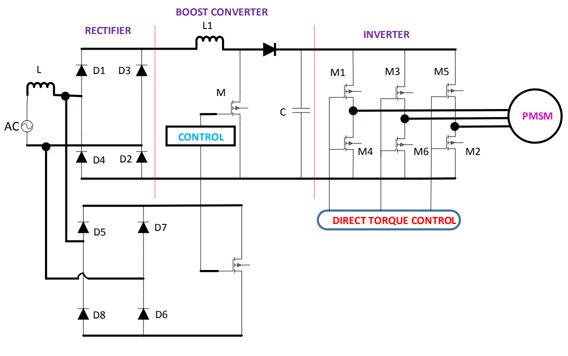


Fig.1.1 Circuit Diagram of Shunt Based Active Power Factor Correction of PMSM.

II. ACTIVE POWER FACTOR CORRECTION CIRCUIT

The proposed circuit maintains the benefits of good PFC by low-frequency switching control structure for DTC controlled PMSM. It associates with two- diode bridge rectifiers, a power switch (MOSFET), an inductor with high inductance and a capacitor. Ordinarily, circuits with a single-diode bridge rectifier affected from severe distortions in the phase angle of the input voltage and current, culminating in very low PF [18]-[21].With the recent developments in the microprocessor and DSP technologies, there is the possibility to implement complex PFC algorithms using these fast processors. In this paper, PIC 16F877 microcontroller is used for providing triggering pulses at suitable time intervals. In most applications, the active PFC controls the input current of the load so that the current waveform has the same frequency, phase and shape mains voltage with no additional harmonics. Active power factor correctors can be single-stage or multi-stage [22]-[24]. This approach is more complex but results in a really good power factor.

In our proposed paper, shunt based Active power factor correction circuit as shown in fig 2.1, with two diode bridge rectifiers connected in parallel is used inorder to reduce the harmonics and to increase the power factor. The switch 'S' is turned on for the short time period in order to cancel the effect of harmonics and to improve the power factor of the ac supply.

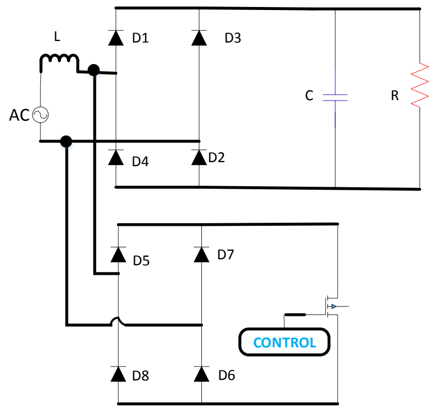


Fig.2.1. Shunt Based Active Power Factor Correction Circuit

2.1 MODES OF OPERATION

The four modes of operation of the proposed circuit has been discussed as follows with the corresponding voltage and current expressions :

1. +VE Half period during transistor conduction
2. +VE Half period during transistor cut-off
3. -VE Half period during transistor conduction
4. -VE Half period during transistor cut-off

2.1.1 +VE Half Period during Transistor Conduction

Fig 2.2 represents an equivalent circuit during positive, power-switch conduction. Power flows through L, D5, the transistor and D8 to constitute a loop.
The charging voltage passes through the inductor is
$V_L(t) = V_{ac}(t)$ (2.1)
The input voltage is $V_{ac}\sin(t)$, and the current flowing through the inductor is

$$i_q(t) = i_{in}(t) = i_{in}(0) + \frac{1}{L}\int_0^t V_L(t)\,dt = i_{in}(0) + \frac{1}{L}V_{ac}(t) \quad (2.2)$$

Substituting t = DTs into (2.2) yields

$$i_q(DT_s) = i_{in}(0) + \frac{1}{T}V_{ac}(DT_s) \quad (2.3)$$

2.1.2 +VE Half-Period during Transistor Cut-Off

In mode 2, the power flows through L, D1 and D4 to compose a loop. The polarity of the inductor voltage is inverted when the transistor cuts off, whereupon the stored energy in the inductor is combined with the power through the rectifier to supply the load. The output voltage is
$V_L(t) = V_0 - V_{ac}(t)$ (2.4)
The input ac voltage is represented by $V_{ac}\sin(\omega t)$, and the current flowing through the inductor is computed as follows

$$i_{in}(t) = i_{in}(DT_S) + \frac{1}{L}\int_{DT_S}^{t} V_L(t)dt$$

$$= i_{in}(T_s) + \frac{1}{L}(V_{ac}(t) - V_0)(t - DT_s) \quad (2.5)$$

2.1.3 -VE Half-Period during Transistor Conduction

In this mode, the direction of the current and voltage is reversed. Thus L, D7, the transistor and D6 make up a loop. The charging voltage and inductor current value can be followed as per equation (2.1- 2.3)

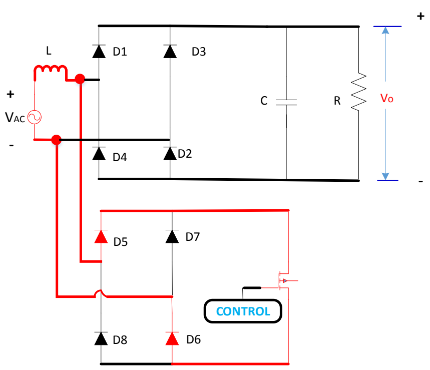


Fig.2.2. +VE half-period during transistor conduction

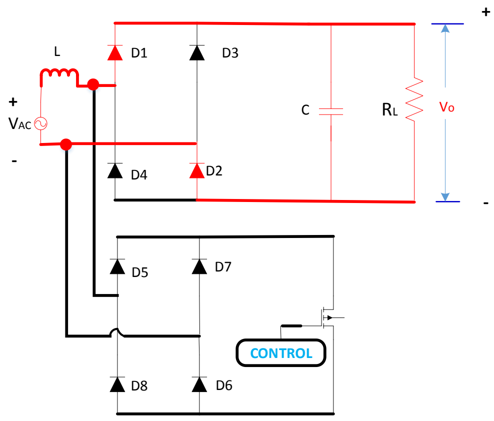


Fig.2.3. +VE half-period during transistor cut-off

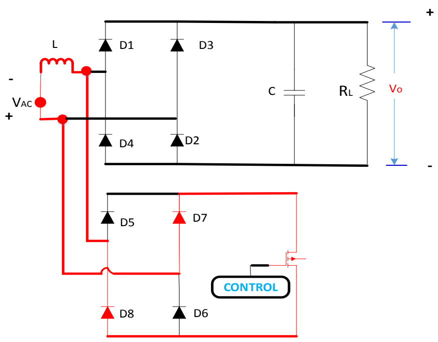


Fig.2.4. –VE half-period during transistor conduction

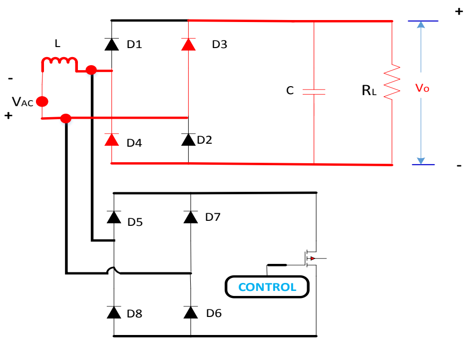


Fig.2.5. -VE half-period during transistor cut-off

2.1.4 -VE Half Period during Transistor Cut-off

As demonstrated in Fig 2.5 transistor cut-off via D3, D2 and L forms a loop, consequently, the polarity of the Inductor voltage has been reversed. The energy stored in the inductor is joined with the power flowing through the rectifier to provide the load. This procedure is identical to that of positive half-period transistor cut-off; however, the polarity of the voltage is reversed. Based on the aforesaid transistor conduction equivalent circuit, the current moves through the circuit only if $V_{ac} > V_L$. During the transistor conduction, the circuit charges inductor, ensuring that current remains in flowing areas with less V_{ac}. Upon transistor cut-off, V_{ac} is added to V, such that the input voltage earlier exceeds V_0.

III. SIMULATION RESULTS

Simulation of the proposed circuit is done using MATLAB / Simulink software as shown Fig 3.1. Simulation parameters of power factor correction circuit been shown in Table 1. The proposed method has been compared with the conventional circuit when only rectifier is connected to PMSM and when inductor is connected in series with rectifier. Table 2 compares the power factor of input supply under various circuit connections and it has been proved that the power factor has been improved using the proposed method almost to unity for various load conditions

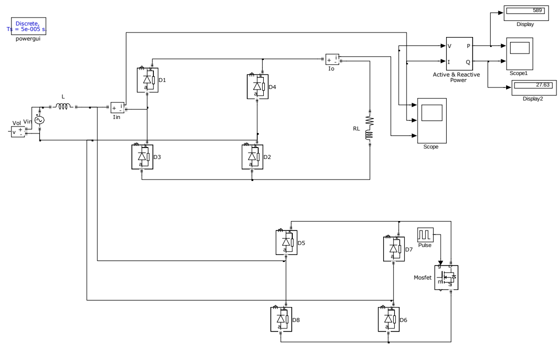


Fig 3.1 Simulation diagram of shunt based active power factor correction

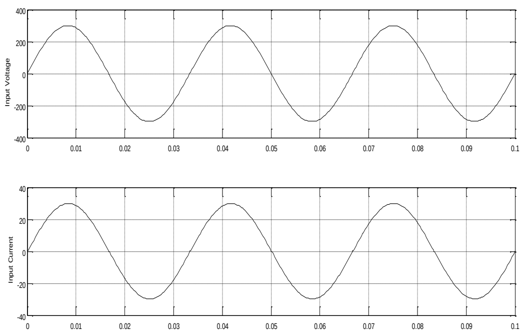


Fig 3.2(a) Simulated response of Input Voltage and Input Current of the Power Factor Correction Circuit.

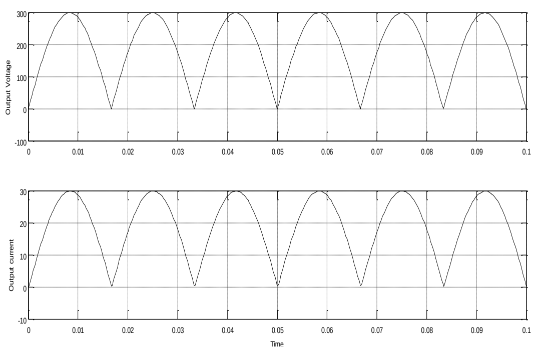


Fig 3.2(b) Simulated response of Output Voltage and Output Current of the Power Factor Correction Circuit.

Table.1 Simulation parameter of power factor correction circuit

Parameter	Specification
Input Voltage	230V
Input Current	5A
R_{Load}	50 ohm
L_{Load}	20 mH
Inductor	5 mH
Duty Cycle for Switch S	20%
Duty Cycle for Switch S1	50%

Table.2 Power Factor Results of various control schemes

S.No	Output Load (Ω)	Single Bridge Rectifier	Single bridge rectifier with Inductor	Shunt semi active PFC
1.	100	0.770	0.781	0.967
2.	150	0.757	0.779	0.938
3.	200	0.750	0.789	0.895
4.	250	0.738	0.785	0.855

Table 3: Simulation Parameter for Direct Torque Controlled PMSM

S.No.	Parameter	Specification
1.	Input Voltage	230V
2.	Speed of the Motor	1000rpm
3.	Flux Linkage	0.1848
4.	Resistance	4.765Ohm
5.	Inductance	0.014 Henry
6.	No. of Poles	4

Fig 3.2(a) and 3.2(b) portrays both input and output voltage along with current waveforms of power factor correction circuit.

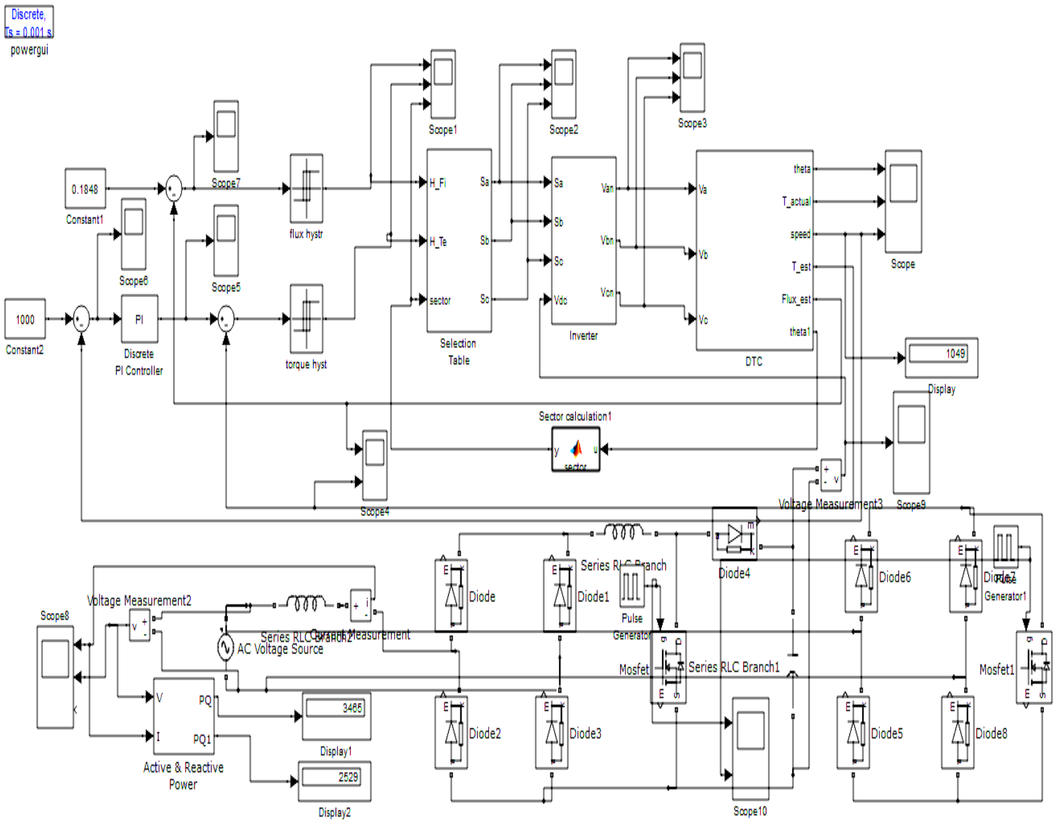


Fig. 3.3 Simulation Diagram of Shunt-Based Active Power Factor Correction Circuit

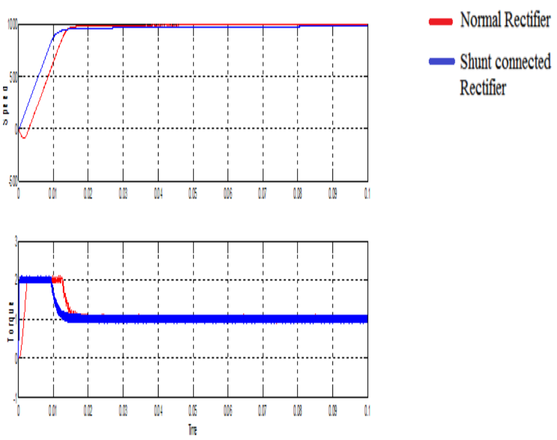


Fig 3.4 Comparison between Direct Torque control and Shunt base- active Power Factor Correction Direct Torque Controlled PMSM

Fig 3.3 shows the complete simulation circuit of proposed converter which includes DTC controlled PMSM drive along with shunt connection. Table 3 shows the parameters of PMSM which has been considered for simulation. The proposed shunt-based, semi-active Power Factor Correction (PFC) circuit for Direct Torque Controlled permanent magnet synchronous motors (PMSM) provides improved power factor in order to improve the effectiveness of controlling the speed and torque of the motor with less distortion which is explicitly shown in fig 3.4.

IV HARDWARE IMPLEMENTATION

Hardware layout of the shunt based active power factor circuit has been shown in the below Fig.4.1. It consists of power supply circuit, controller circuit, driver circuit and converter circuit, shunt connected rectifier boost converter and inverter circuit.

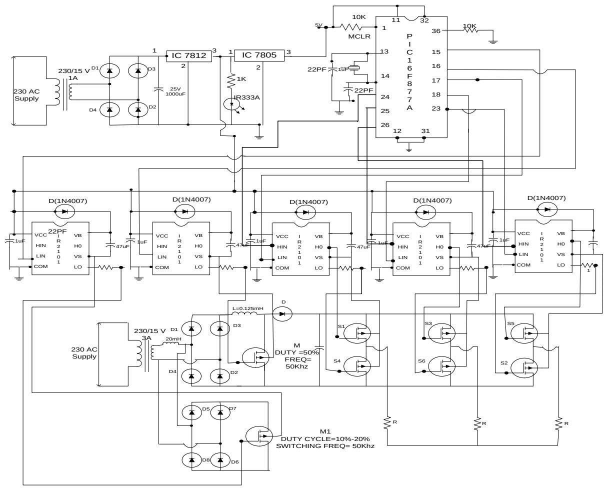


Fig.4.1 Hardware Circuit Layout

In shunt based active power factor correction circuit, voltage and current wave of the input side has been measured. Phase angle between the voltage and current waveform has been compared with and without shunt connected rectifier.

Fig.4.2 Hardware of Proposed Circuit

The voltage and current waveform of the normal rectifier and angle between them has been shown in the Fig.4.3 where the current waveform has some distortion. The voltage and current waveform of shunt connected rectifier and angle between them has been shown in Fig.4.4. Distortion in conventional circuit as Fig 4.3 has been mitigated in proposed circuit Fig 4.4.

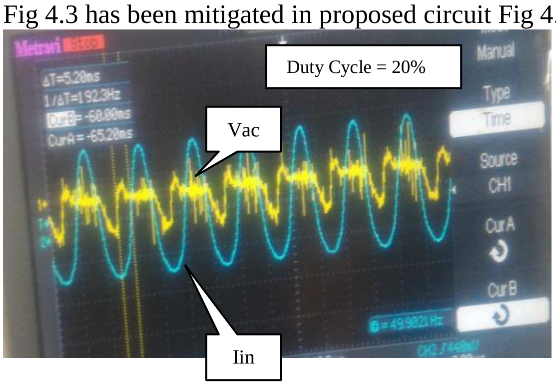
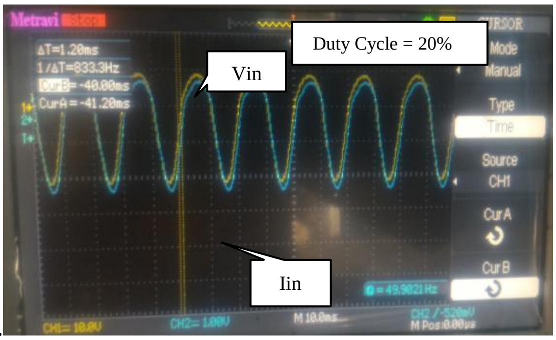
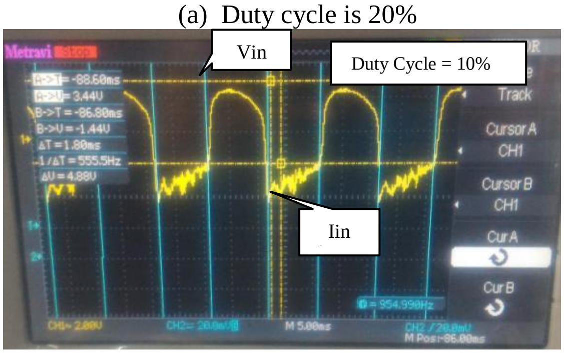


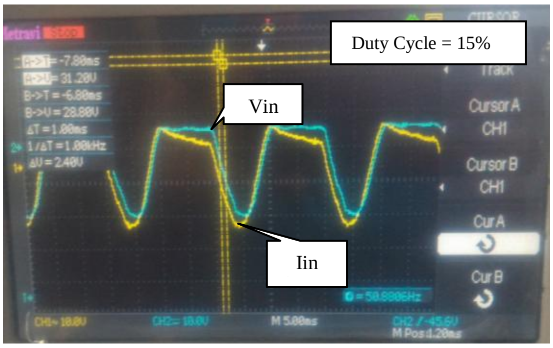
Fig.4.3 Phase angle between voltage and current without shunt connected rectifier.



(a) Duty cycle is 20%



(b) Duty cycle is 10%



(c) Duty cycle is 15%

Fig.4.4 (a), (b) & (C) Phase angle between voltage and current with shunt connected rectifier with different duty cycles.

V CONCLUSION

In this paper, a method for improving power factor and performance of direct torque controlled PMSM has been implemented. Sequential explanation of principle of operation, modes of operation for power factor correction circuit has been presented both in simulation using MATLAB/ Simulink and hardware. In comparison of three circuits, the proposed shunt-based active power factor circuit enables power factor improvement where the shunt based active power factor correction circuit reduces the reactive power consumption. The main purpose of this hybrid topology is to meet our daily demand effectively and to get an uninterrupted power supply. Filter size and losses are reduced considerably in this proposed system and also the performance of PMSM has been improved.

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