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# Speed Control of Permanent Magnet DC Motor using Bridgeless Rectifier Based Fuzzy Controller

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**ABSTRACT**

This Paper analyses a topology consisting of a three-phase bridgeless rectifier for a PMDC motor. The three-phase Bridgeless rectifier is a non-generative boost type rectifier. Many switching methods are generally taken into an account for the Bridgeless rectifier’s operation with the unity power factor that aims to provide the undistorted power to the PMDC motor. The Bridgeless rectifier is able to convert a variable input AC voltage amplitude to a constant armature DC voltage, while controlling the input current to be sinusoidal and in phase with the input voltage. The Bridgeless rectifier was able to maintain a constant armature voltage at the output for input voltages as low as half the rated input voltage and for an equivalent output power of half the rated output power. The Fuzzy controller is used to regulate the speed of PMDC motor. The Simulation results show that the proposed model could realize low total harmonics distortion, high input power factor, speed regulation and the simulation results show it is effective and feasible output.

***Keywords—PMDC motor; bridgeless rectifier; THD; power factor correction;***

## I. INTRODUCTION

In recent year, PMDC motors are used in variety of application such as heater, wiper and personal computer. In addition, PMDC motors have no requirement for winding field so that size of PMDC motor is smaller than conventional DC motor and cost of PMDC motors are also relatively lower. PMDC motor is direct control, where the rotation speed of the shaft is proportional to the applied voltage of motor, while the instantaneous torque can be linearly controlled by controlling the armature current. PMDC motor drives are build based on two types of power electronics converters- either phase controlled rectifier or switched mode DC/DC converter. Controlled rectifiers are generally used for the speed control of PMDC motor. A power converter uses semiconductor devices such as diodes, MOSFETs and IGBTs to achieve the power conversion and also control the speed of PMDC motor using many switching methods. Higher efficiency can be achieved by using the bridgeless boost topology. The efficiency of various PFC topologies is studied based on its classification. Two types of PFC topology classification are proposed namely the full-bridge with 1 DC/DC converter and a Bridgeless converter. The bridgeless rectifier efficiency can be improved up to 8% and in some cases up to 10% [4].

Recent trends in power electronics have shown that elimination of diode bridge rectifiers at the front end improves power quality. They have the advantage of Total Harmonic Distortion (THD) decreasing with input diode reduction Bridgeless Topologies results in reduced conduction loss, reduced harmonics, improved Power factor and efficiency[10][13]. To designed the combination of Adaptive controller and Fuzzy controller. The proposed controller is compared with adaptive controller and fuzzy controller for PMDC motor. Comparing the proposed controller to adaptive controller, observe that the percent maximum overshoot and settling time are improved. On the other hand, comparing proposed controller to fuzzy controller, observe that the steady state error improved in proposed controller [7]. The analysis to reduce the harmonic current pollution which caused by non-linear loads in a power system can rectify using a DC link Active Power Filter [12]. In this paper [13], designed a three-phase bridgeless boost power factor correction (PFC) circuit. This circuit consists of three separate single-phase bridgeless boost PFC converters are paralleled at the output, and the output capacitor is shared by three converters. New modeling and control technique for three-phase boost converter for efficient transfer of energy from an irregular input power source to a battery storage device or a DC link [10]. The circuit can provide purely active power conversion of band-limited input voltage source to a DC link for low power application. This paper solution enables real-time variation of the generator loading using high efficiency switching power devices. The new Hybrid Switching Method enables new Three-Phase AC-DC boost converter topology, the true bridgeless PFC Converter consisting of just three switches and three magnetic component at a much higher efficiency. The goal of developing AC-DC converters with low THD and Power Factor Correction (PFC) feature in a single power processing stage and without a mandatory full bridge rectifier has enormous advantages with high efficiency.

## II. THREE PHASE AC-DC BRIDGELESS RECTIFIER

A new modelling and control technique for a three-phase bridgeless boost converter is presented for efficient transfer of energy from an AC input power source to control the speed of PMDC Motor. The gate pulse of bridgeless rectifier can be generated according to the switching states of MOSFETs. Fuzzy controller is used to regulate the PMDC motor speed. Traditional ac-dc power converters have issues such as poor power factor and voltage/current distortion. The analysis and design of high power factor three-phase rectifiers and associated control techniques have been presented. Different control methods and circuit topologies have been proposed for bridgeless rectifier and the widely used in PI and fuzzy controller technique. The block diagram and three phase-phase bridgeless boost converter are shown in figure.2 and figure.2.

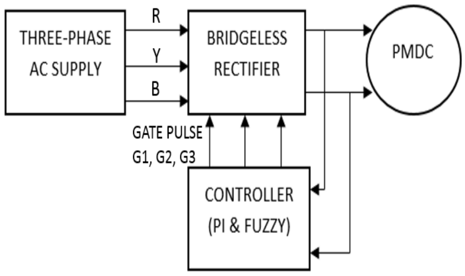


Figure.1 Block Diagram of Bridgeless Rectifier

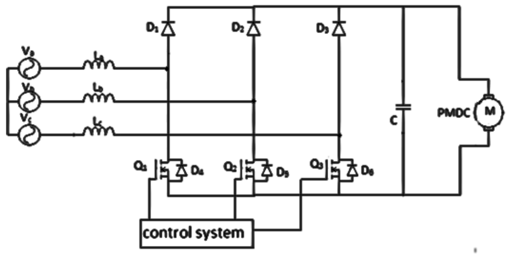


Figure.2 Circuit Diagram of Bridgeless Rectifier

The above block diagram explains the function of the three phase bridgeless rectifier fed PMDC motor. Here the power source output connected with the controller and the output voltage from the power electronic switches ($G_1$, $G_2$, $G_3$) are also connected to the controller. The controller controls the PWM switching driver to give proper pulse width to the switches, as per the PWM signal the switches converts the irregular AC voltage to required DC voltage for control the speed of PMDC motor.

The circuit diagram shows the proposed model of three phases AC to DC bridgeless boost converter with the controller. In this proposed model three MOSFET switches are connected at the lower legs and similarly three diodes are connected at upper legs. The three input AC supply phases are connected in corresponding three legs.

The phase inductors were connected in each phase for energy storage purpose and a filter capacitor is used to reduce the current distortions, voltage ripples etc. In this circuit a feedback controller is used, so the output voltage and the current become a controlled one. The load connected at the end of the circuit, which is a PMDC motor drive.

## III. OPERATING PRINCIPLE AND THEIR MODES

Compared to a full-bridge converter, the efficiency of these three-phase boost converter can be improved by 8% - 10%, especially for low power applications. Furthermore, to reduce the switching losses, only one MOSFET is switched at each time instant, while the other two are kept ON/OFF depending on the relative voltages of the corresponding phases.

Input phase voltages $E_r$, $E_y$ and $E_b$ are connected to source inductances which are connected in series. The corresponding phase-to-phase voltages $E_{ij}(t)$ defined as follows

$$E_{ij}(t) = E_i(t) – E_j(t)$$

Where i,j =r,y,b and $i \neq j$

In the following, a brief review of the circuit operation is provided, followed by derivation of the nonlinear resistances seen by input sources $E_r$, $E_y$, and $E_b$ using an averaging method. Let us consider a typical case when $E_{ry} \geq 0$, $E_{rb} \geq 0$, for which $Q_1$ is switching in the ON/OFF mode while $S_2$ and $S_3$ are kept ON.

**The circuit operates in three modes:**

Let us consider in mode 1 case when $E_{ry} \geq 0$,$E_{rb} \geq 0$, for which S1 is switching in the ON/OFF mode while S2 and S3 are kept ON.As shown in Fig. when all switches are ON, none of the diodes D1-D3 can conduct. In this case, the energy drawn from the input sources is stored in the magnetic fields of the inductors. This mode can be considered as rectification process. Because this voltage drawn between the source, inductances and switches.

In this mode 2 operates under three switching conditions, when $E_{yb} \geq 0$, S1 is turned OFF, S2 is turned OFF and S3 is kept ON as long. When $E_{yb}$<0, S3 is turned OFF and S2 is kept ON. For the case when $E_{yb}$ =0, both S2 and S3 are kept ON. Assuming $E_{yb} \geq 0$, current flows through diode D1, PMDC motor and back through the antiparallel diode of D2 and switch S3, as shown in Fig.4.5. In this case, the stored energy in the inductors together with energy drawn from the input sources is fed to the battery. This condition is continued until $L_y$ current reaches 0.This condition suits for both $E_{ry}$ > 0 and $E_{br}$ > 0.

In this mode 3, the remaining stored energy in $L_r$ and $L_y$ along with the energy coming from $E_a$ and $E_c$ charge the battery until the inductors are totally discharged. After the inductors are get discharged then the mode 1 begins with charging the inductors and the currents flows through only switches.

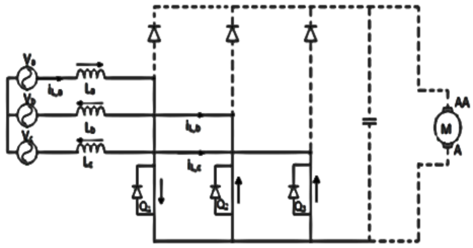

Figure.3 Mode of circuit operation when $S_1$, $S_2$, and $S_3$ are all ON

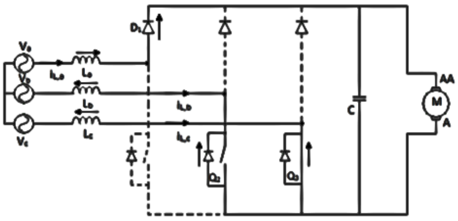

Figure.4 Mode of circuit operation when $S_1$ and $S_2$ are OFF and $S_3$ is ON

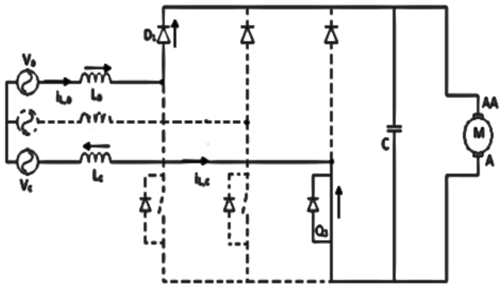

Figure.5 Mode of circuit operation when $S_1$ and $S_2$ are OFF and $S_3$ is ON, and the inductor current of phase b reaches zero ($i_{Ly} = 0$)

## IV. STATES OF SWITCHES FOR DIFFERENT MODES OF OPERATION

One simple and easy way to control the speed of a motor is to regulate the amount of voltage across its terminals and this can be achieved using "Pulse Width Modulation" or PWM.

TABLE 4.1 Switching States for Different Modes

| PHASE-TO-PHASE VOLTAGE | $S_1$ | $S_2$ | $S_3$ | MODE |
|---|---|---|---|---|
| **Any combination of voltages** | **ON** | **ON** | **ON** | **1** |
| $E_{rb} \geq 0$, $E_{yb} \geq 0$ | **OFF** | **OFF** | **ON** | **2** |
| $E_{ry} \geq 0$, $E_{by} \geq 0$ | **OFF** | **ON** | **OFF** | **2** |
| $E_{yr} \geq 0$, $E_{br} \geq 0$ | **ON** | **OFF** | **OFF** | **2** |
| $E_{rb} \geq 0$, $E_{yb} \geq 0$ , **either** $i_{L,r}=0$ **or** $i_{L,y}=0$ | **OFF** | **OFF** | **ON** | **3** |
| $E_{ry} \geq 0$, $E_{by} \geq 0$, **either** $i_{L,r}=0$ **or** $i_{L,b}=0$ | **OFF** | **ON** | **OFF** | **3** |
| $E_{yr} \geq 0$, $E_{br} \geq 0$, **either** $i_{L,y}=0$ **or** $i_{L,b}=0$ | **ON** | **OFF** | **OFF** | **3** |

The above table summarizes the above methods of operation with all possible arrangements of phase-to-phase voltages. From this table, it is evident that the switches are all ON in mode 1 regardless of the phase-to-phase voltages. As soon as one of the switches is turned OFF, the states of other switches are changed according to the corresponding phase-to-phase voltages. Without loss of generality, the developments presented in this section are for the case when $E_{rb} \geq 0$ and $E_{yb} \geq 0$ (first, second and fifth rows in Table. The current profiles for charging and discharging of the inductors in a typical operating mode are shown in Table 4.1.

## V. DESIGN OF FUZZY LOGIC CONTROLLER

Fuzzy controller rules which are play a very important role for controller simulation are obtained from the analysis of the circuit behavior. In their formulation it must be considered that, By using this controller we improve the bridgeless converter performances in terms of dynamic response and robustness. Fuzzy Logic Controller is designed to control the output of bridgeless ac-dc converter. In the fuzzy logic system two input variables, error (e) and change of error (ce) and one output variable (u) is duty cycle of PWM output are shown in figure.6. For each input and output variable fuzzy sets must be defined. The seven fuzzy subsets PS (Positive Small), PM (Positive Medium), PB(Positive Big), ZE (Zero), NS (Negative Small), NM (Negative Medium), NB (Negative Big) have been chosen for input variables error (e) and change of error (de). The Triangular shape has been adopted for the membership functions; the value of each input and output variable is normalized in the range [-1,1] by using suitable scale factors.

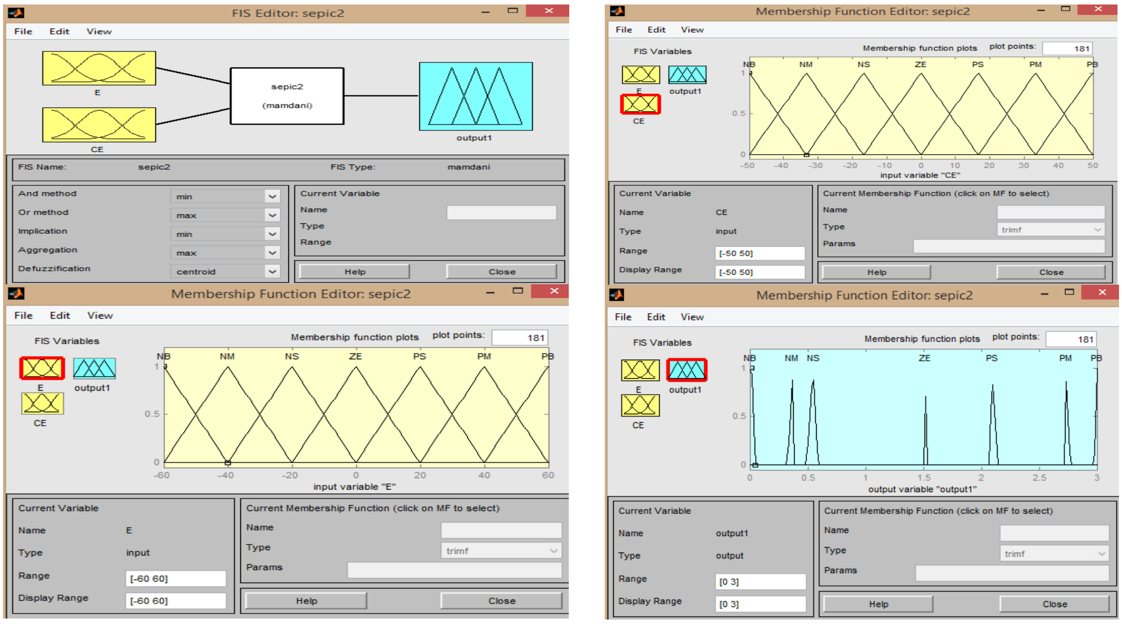


Figure.6 Membership Functions plots of error, change in Error and duty cycle ratio

When the output voltage is far from the set point i.e error(e) is NB or PB, the controller must be do the strong corrective action i.e output duty cycle close to zero or have the dynamic response as fast as possible, obviously taking into account current limit specifications of the system.

Table 2: Rules for error and change of error

| E \ CE | NB | NM | NS | ZE | PS | PM | PB |
|---|---|---|---|---|---|---|---|
| NB | NB | NB | NB | NB | NM | NS | ZE |
| NM | NB | NB | NB | NM | NS | ZE | PS |
| NS | NB | NB | NM | NS | ZE | PS | PM |
| ZE | NB | NM | NS | ZE | PS | PM | PB |
| PS | NM | NS | ZE | PS | PM | PB | PB |
| PM | NS | ZE | PS | PM | PB | PB | PB |
| PB | ZE | PS | PM | PB | PB | PB | PB |

Second Condition, when output voltage error of the system approaches to zero i.e error (e) is ZE, NS, PS, NM, PM then in order to ensure stability around the working point, the current error should be properly taken into account. When the current value approaches the limit value, suitable rules must be introduced to preventing the large overshoots. The rules of fuzzy control for error and change of error can be referred in the table 2.

## VI. SIMULATION RESULTS

### a. PI Controller

In the simulation of three phase bridgeless rectifier fed PMDC motor with PI controller single stage topology before power factor correction (Figure) has rectifier circuit on the input side which is converting AC input into constant DC.

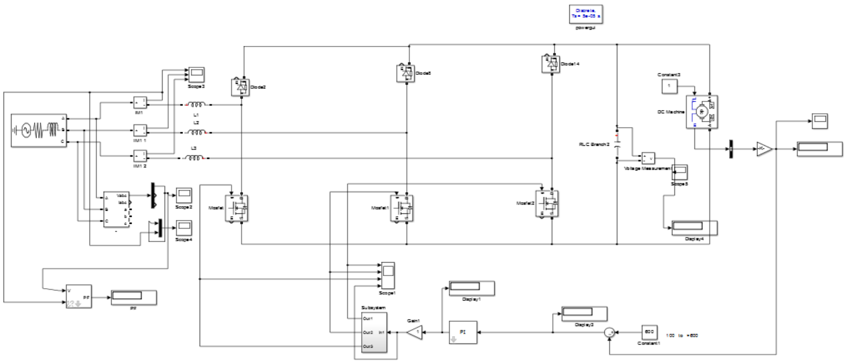

Figure.7. Simulation circuit diagram with PI controller

The input voltage of circuit diagram is 100v, 50Hz, AC supply and each phase shifted by 120$^{o}$. The figure 8. Shows input pulses to switch S1, S2 and S3. The open pulse is generated by using input voltage and switching method.

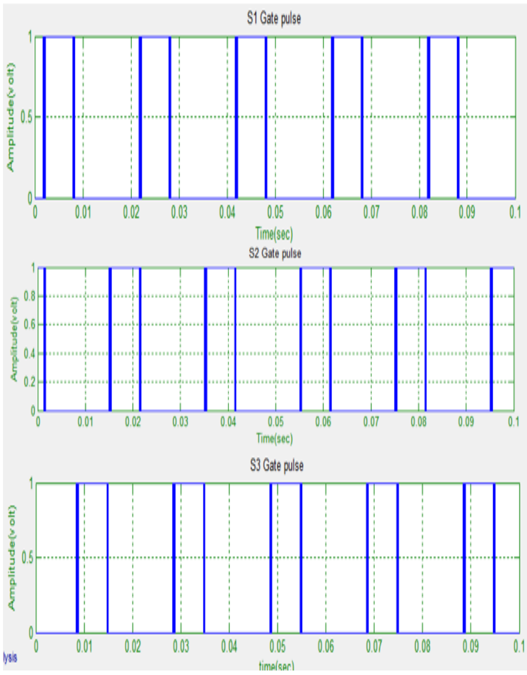


Figure.8. Gate pulse for three switches

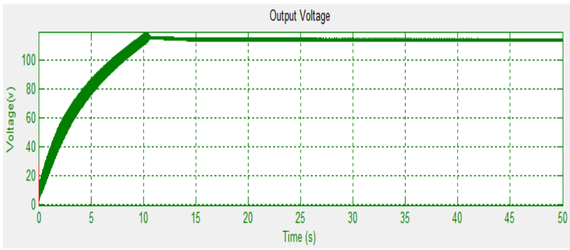


Figure.9. Output voltage of bridegeless rectifier with PI controller

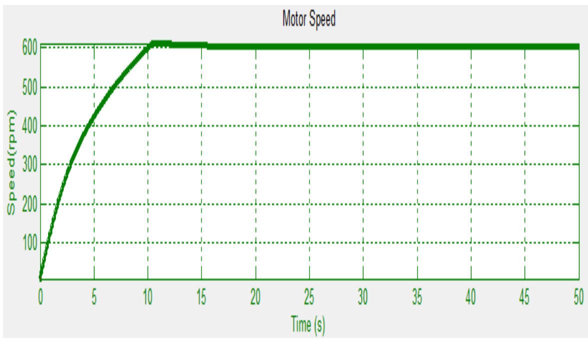


Figure.10. PMDC motor speed

The PMDC motor speed and armature voltage using bridgeless Rectifier is shown in figure 9 and figure 10. For a speed up to the base speed, the armature voltage is varied and the torque is maintained constant (N=600rpm). Once the rated armature voltage is applied, the speed-torque relationship follows the nature characteristic of the motor and the power (= torque × speed) remains constant. As the torque demand is reduced, the speed increases.

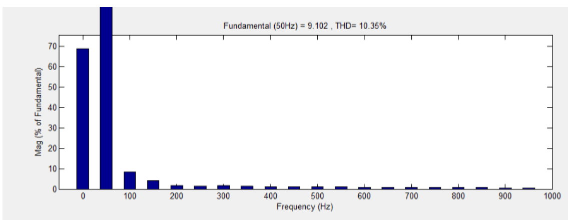


Figure.10. Total Harmonics Distortion

The above figure 6.6 shows that harmonics can be very small in this converter so the active power can be transferred from variable source to DC link.

**b. Fuzzy logic controller**

In the simulation of three phase bridgeless rectifier fed PMDC motor with PI controller single stage topology before power factor correction (Figure 6.8) has rectifier circuit on the input side which is converting AC input into constant DC.

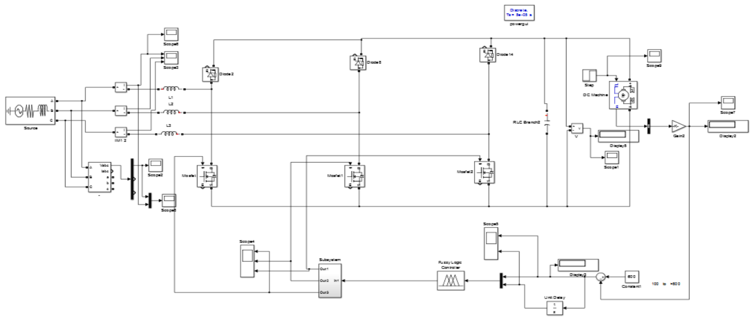

Figure.11. Simulation circuit diagram with fuzzy logic controller

The speed of PMDC motors changes with the load torque. To maintain a constant speed, the armature voltage should be varied continuously by varying the delay angle of ac-dc converters. In practical drive systems it is required to operate the drive at a constant torque or constant power, in addition, controlled acceleration and deceleration are required. Most industrial drives operate as closed-loop feedback systems.

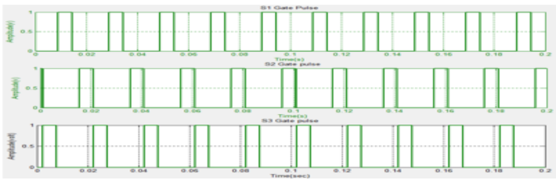

Figure.12. Gate pulse for three switches

Only one switch is ON at each time instant using PI controller. The output voltage and current of closed loop three phase bridgeless rectifier shown in figure 6.10.

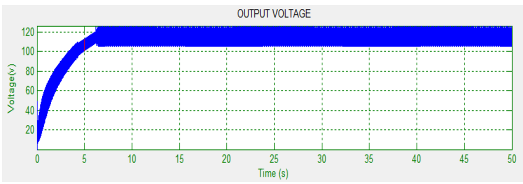


Figure.13. Output voltage of bridegeless rectifier with fuzzy controller

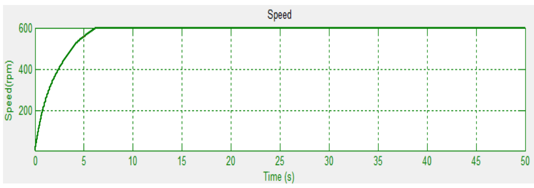


Figure.14. PMDC motor speed

The simulation diagram of a closed-loop bridgeless rectifier fed PMDC motor drive is shown in figure 11. The speed controller responses with an increased control signal $V_c$, change the delay angle of the converter, and increase the armature voltage of the motor. The input side voltage and current waveforms of closed loop bridgeless rectifier fed PMDC motor drive is shown in figure.15.

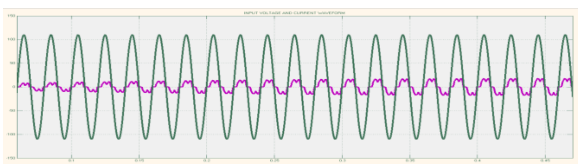

Figure.15. Input side voltage and current waveforms

Here the input side voltage and current waveforms are compared and the angle(δ) between voltage and current waveforms in the input side is closed to zero. So that the power factor is closed to unity.

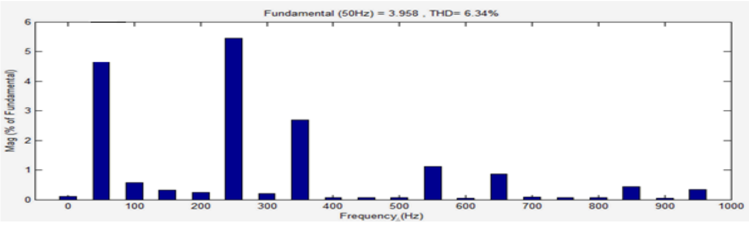


Figure .16. Closed loop Total Harmonic Distortion

The above figure.16. Shows that harmonics can be very small compared to closed loop bridgeless rectifier with PI controller.

**VII. CONCLUSION**

This work developed a three phase AC input voltage into controlled an output voltage with a reduced number of switches for speed controlling PMDC motor with Fuzzy controller. Most previously three-phase bridgeless rectifier have a boost converter input section. The main objective is to achieve power factor correction at the input side of AC-DC bridgeless Rectifier there by regulating the speed of PMDC motor and input current which achieves a near sinusoidal waveform. This proposed system is simulated in MATLAB Simulink in closed loop and the power factor is measured. The closed loop circuit has controlled using PI and Fuzzy controller. This power factor correction improves the circuit efficiency. The total harmonics distortion of fuzzy controller is reduced to 6.34%.

In this work, the operation of this fundamental Half-bridge three-phase converter topology and a method of analyzing its steady-state operation were presented with PMDC motor as load. The feasibility of the converter was confirmed with results obtained from a Simulation prototype using MATLAB.

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