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Comparative Study of PID Based VMC and Fuzzy Logic Controllers for Flyback Converter

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Abstract - In this paper performance of flyback converter by using PID controller and Fuzzy controller are studied, compared and analyzed. The above study is done for 200W, 230V A.C input 48V DC output. Design of fuzzy controller is based on the heuristic knowledge of converter behaviour, and tuning of fuzzy inference requires some expertise to minimize unproductive trial and error. The design of PID control is based on the frequency response of the converter. For the DC-DC converters, the performance of the fuzzy controller was superior in some respects to that of the PID controller. The fuzzy controller is easily to develop, they cover a wide range of operating conditions, and they are more readily customizable in natural language terms. Simulation is done in Matlab environment to show the performance variations of above mentioned converters using both Fuzzy & PID controllers.

Keywords - Voltage Mode Control (VMC), Flyback converter, PID (Proportional Integral Derivative) Controller, Fuzzy Controller.

I. INTRODUCTION

In the past few years the dc-dc converters are controlled using analog integrated circuit technology and linear system design techniques. Conventional control techniques used for dc-dc converters are PID controllers which tend to provide linear characteristics [1]. But DC-DC converters exhibit nonlinear characteristics. The causes of nonlinearity in the power converters include a variable structure with in a single switching period, saturating inductances, voltage clamping, etc. So whenever there is any change in system, any parameter variations or even load disturbances PID controllers tend to be less [1-6]. To control non linear systems satisfactorily non linear controllers are often developed. It is always desirable for buck converters with constant output voltage that the output voltage remains unchanged in both steady and transient operations whenever the supply voltage or load current is disturbed. This condition is known as zero-voltage regulation, which means that the output voltage is independent of the supply voltage and the load current.

To achieve zero-voltage regulation, the choice of the control method plays a very critical role in the performance of converters. The most commonly used method in converters is the direct duty ratio control. This method is too complex to be practically executed. Another popular method is the current control mode

control. But this method cannot eliminate the load current disturbances. This can be avoided by using fly back converter. Though fly back converter is derived from the buck-boost converter, we can operate it as buck converter by reducing duty cycle. The flyback converter provides the isolation and short circuit protection by a single switch. The main disadvantage in fly back converter operating in continuous conduction is output power is not proportional to the duty cycle hence we are operating the fly back converter in discontinuous mode.

II. FLYBACK CONVERTER

The flyback converter converts an input voltage into a regulated lower or higher-valued output voltage depending on its transformer's turns ratio. A simplified circuit diagram and associated operating waveforms are shown in Fig. 1(a) and Fig. 2(a), 2(b), 2(c), 2(d). Input to the circuit may be unregulated dc voltage derived from the utility ac supply after rectification and some filtering. The ripple in dc voltage waveform is generally of low frequency and the overall ripple voltage waveform repeats at twice the ac mains frequency. Since the SMPS (Switch Mode Power Supply) circuit is operated at much higher frequency (in the range of 100 kHz) the input voltage, in spite of being unregulated, may be considered to have a constant magnitude during any high frequency cycle. A fast switching device ('S'), MOSFET, is used with fast dynamic control over switch duty ratio (ratio of ON time to switching time-period) to

maintain the desired output voltage. The transformer, in Fig. 1(a), is used for voltage isolation as well as for better matching between input and output voltage and current requirements. Primary and secondary windings of the transformer are wound to have good coupling so that they are linked by nearly same magnetic flux. The primary and secondary windings of the fly-back transformer don't carry current simultaneously and in this sense flyback transformer works differently from a normal transformer. In a normal transformer, under load, primary and secondary windings conduct simultaneously such that the ampere turns of primary winding is nearly balanced by the opposing ampere-turns of the secondary winding (the small difference in ampere-turns is required to establish flux in the non-ideal core). Since primary and secondary windings of the flyback transformer don't conduct simultaneously they are more like two magnetically coupled inductors and it may be more appropriate to call the flyback transformer as inductor-transformer.

III. MODES OF CIRCUIT OPERATION

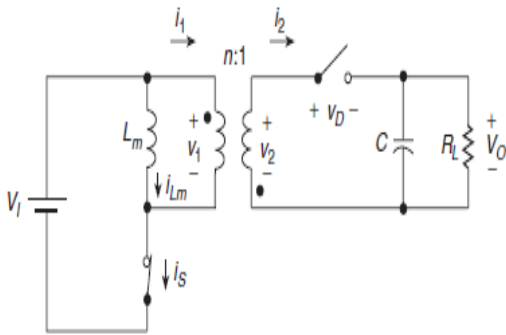


Fig 1(a) : Equivalent circuit of flyback converter in Mode 1

Mode-1: of circuit operation starts , when switch 'S' is on, the primary winding of the transformer gets connected to the input supply with its dotted end connected to the positive side. At this time the diode 'D' connected in series with the secondary winding gets reverse biased due to the induced voltage in the secondary (dotted end potential being higher). Thus with the turning on of switch 'S', primary winding is able to carry current but current in the secondary winding is blocked due to the reverse biased diode. The flux established in the transformer core and linking the windings is entirely due to the primary winding current.

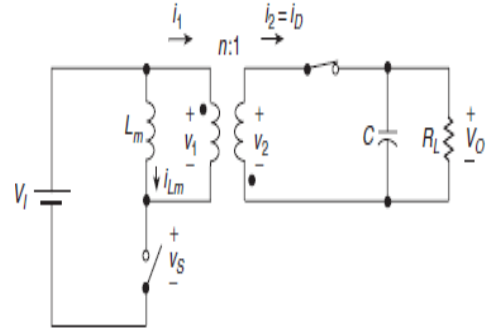


Fig.1 (b) : Equivalent circuit of flyback converter in Mode 2

Mode-2: of circuit operation starts when switch 'S' is turned off after conducting for some time. The primary winding current path is broken and according to laws of magnetic induction, the voltage polarities across the windings reverse. Reversal of voltage polarities makes the diode in the secondary circuit forward biased.

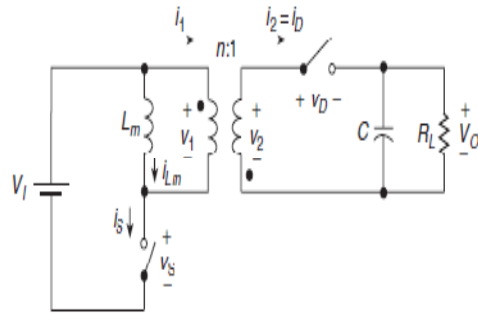


Fig 1(c) : Equivalent circuit of flyback converter in Mode 1

Mode 3: During discontinuous mode, after complete transfer of the magnetic field energy to the output, the secondary winding emf as well as current falls to zero and the diode in series with the winding stops conducting. The output capacitor however continues to supply uninterrupted voltage to the load. This part of the circuit operation has been referred to as Mode-3 of the circuit operation.

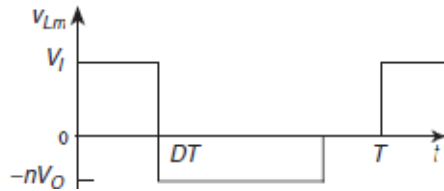


Fig 2(a) : Voltage across magnetizing inductance

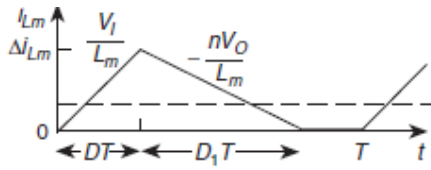


Fig 2(b) : Current through magnetizing inductance

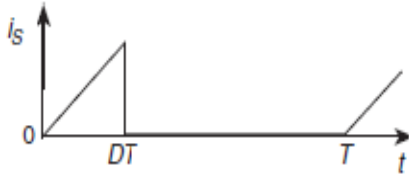


Fig 2(c) : Current through switch



Fig 2(d) : Current through diode

Referring to above figures and using the volt-second balance for V_{Lm} ,

$$V_I DT = nV_O D_1 T, \quad (1)$$

$$M_{VDC} = \frac{V_O}{V_I} = \frac{I_I}{I_O} = \frac{D}{nD_1}. \quad (2)$$

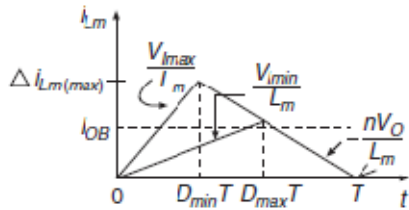


Fig. 3: Waveform of the current through the magnetizing inductance.

At CCM/DCM boundary

$$M_{VDCB} = \frac{D_B}{n(1-D_B)} = \frac{D_B}{n} \sqrt{\frac{R_L}{2f_s L_{ms}}}. \quad (3)$$

The minimum value of the magnetizing inductance peak current at the CCM/DCM boundary occurs at $D = D_{Bmax}$.

$$\Delta i_{Lm(min)} = \frac{nV_O(1-D_{Bmax})}{f_s L_{m(max)}}. \quad (4)$$

The dc current through the magnetizing inductance at the CCM/DCM boundary is

$$I_{LmB} = \frac{\Delta i_{Lm(min)}}{2} = \frac{nV_O(1-D_{Bmax})}{2f_s L_{m(max)}}. \quad (5)$$

The energy transferred from the input dc voltage source V_I to the magnetizing inductance during one cycle for the boundary case is

$$W_{OB} = \frac{L_{m(max)} \Delta i_{Lm(min)}^2}{2}, \quad (6)$$

$$\begin{aligned} P_{OB} &= \frac{W_{OB}}{T} = f_s W_{OB} = \frac{f_s L_{m(max)} \Delta i_{Lm(min)}^2}{2} \\ &= \frac{f_s L_{m(max)} n^2 V_O^2 (1-D_{Bmax})^2}{2f_s^2 L_{m(max)}^2} = \frac{n^2 V_O^2 (1-D_{Bmax})^2}{2f_s L_{m(max)}}. \end{aligned} \quad (7)$$

The dc power transferred from the converter to the load at the boundary can be expressed as

$$P_{OB} = \frac{V_O^2}{R_{Lmin}}. \quad (8)$$

$$L_{m(max)} = \frac{n^2 R_{Lmin} (1-D_{Bmax})^2}{2f_s} = \frac{n^2 V_O (1-D_{Bmax})^2}{2f_s I_{OB}}. \quad (9)$$

The peak-to-peak value of the capacitor current is

$$I_{CpP} = I_{DM} = \frac{nDV_I}{f_s L_m} = \frac{nV_O D_1}{f_s L_m}, \quad (10)$$

Resulting in the peak-to-peak value of the voltage across r_C ,

$$V_{rcpp} = r_C I_{DM} = \frac{r_C nDV_I}{f_s L_m} = \frac{r_C nV_O D_1}{f_s L_m}. \quad (11)$$

The voltage across capacitance

$$V_{cpp} = \frac{\Delta Q_{max}}{C_{min}} = \frac{I_{Omax} D_{max} T}{C_{min}} = \frac{V_O D_{max}}{f_s R_{Lmin} C_{min}}, \quad (12)$$

IV. DESIGN EXAMPLE FOR FLYBACK CONVERTER

The proposed PFC circuit is designed according to the following parameters.

Total output power (P_o)	= 200 W
Input voltage (V_i)	= 90- 230 V
Output voltage (V_o)	= 48 V
Resistance (R_L)	= 11.5ohms
Line frequency	= 50Hz
Switching frequency	= 100 KHz

From eq (16) we can calculate the M_{vdc}

$$V_{max} = 1.414 * 90 = 127.27.$$

$$M_{vdc} = \frac{48}{127.27} = 0.377 \quad (13)$$

Assume efficiency = 0.85 and $D_{max} = 0.5$

From eq (17) we can get the turns ratio (n)

$$n = \frac{(0.85 * 0.5)}{(1 - 0.5) * 0.377}$$

$$n = 2.8$$

Pick n=3 (14)

From eq (23) we can get the magnetizing inductance (L_m)

$$L_m = 129 \text{ e-6H.} \quad (15)$$

From eq (26) we can get the filter capacitance value (C)

$$C = \frac{(0.5 * 48)}{(100 * 11.5 * 0.1 * 10^3)}$$

$$C = 220 \text{ e-6F.} \quad (16)$$

we already know that $\frac{V_1}{V_2} = n$

$$V_1 = 3 * 48$$

$$V_1 = 144. \quad (17)$$

V. VOLTAGE MODE CONTROLLER

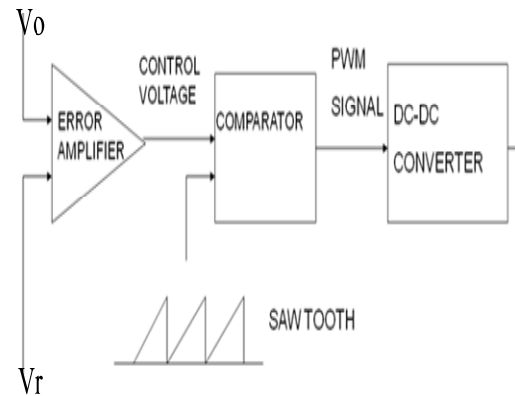


Fig. (4) : Closed loop feedback for VMC using PID controller

Fig. (4) Represents closed loop feedback control. In this control scheme the converter output voltage is sensed and subtracted from an external reference voltage e in an error amplifier. Here error amplifier works as PID controller. The amplifier produces a Control voltage that is compare to constant amplitude saw tooth waveform. The comparator produces a PWM signal that is fed to drivers of controllable switches in the DC-DC converters The duty ratio of the PWM signal depends on the value of the control voltage. The frequency of the PWM signal is the same as the frequency of the saw-tooth waveform. The control of the Switch duty ratio adjusts the voltage across the inductor and hence the inductor current brings the output voltage to its reference value.

V. FUZZY CONTROLLER

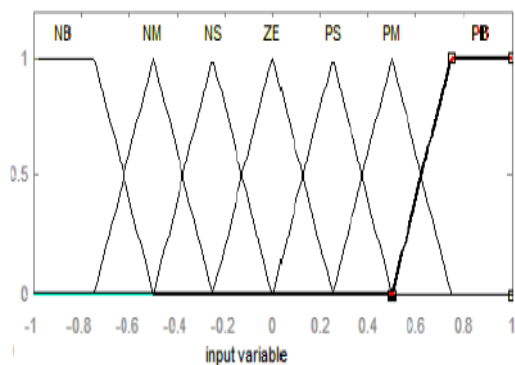


Fig. (5) : Member ship functions for e and ce

The control rules for the dc–dc converter in Table I resulted from an understanding of converter behaviour. A typical rule can be written as follows.

If e is NB and ce is PS then output is ZE

Where are the labels of linguistic variables of error (e), change of error (ce) and output respectively, ce and output represent degree of membership. To obtain the control decision, the max-min inference method is used. It is based on the minimum function to describe the AND operator present in each control rule and the maximum function to describe the OR operator. Control rules are given below.

Rule Table For the Fuzzy Controller

		error(e)						
		NB	NM	NS	ZE	PS	PM	PB
change in error(ce)	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

VI. SIMULATION RESULTS

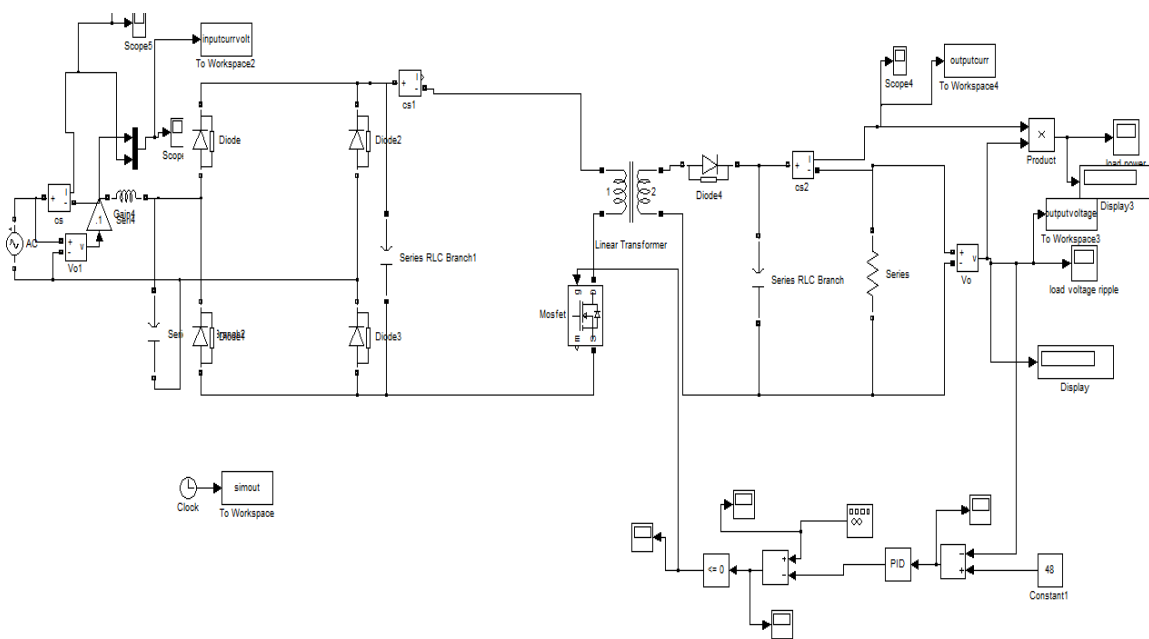


Fig. (6) : Simulink Model of AC to DC Flyback Converter with PID based VMC in MATLAB

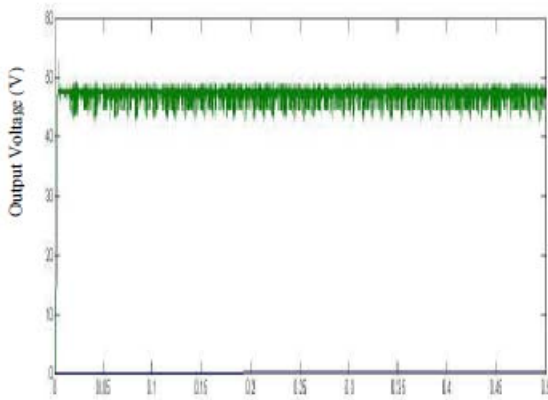


Fig. (7) Output Voltage Time (ms)

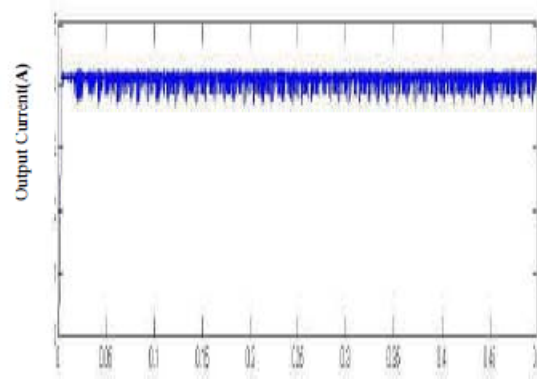


Fig. (8) Output Current Time (ms)

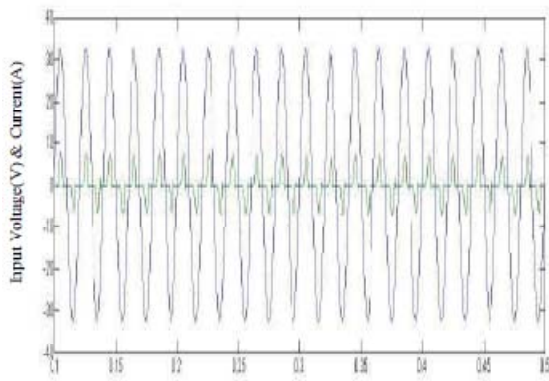


Fig. (9) input Current & Voltage Time(ms)

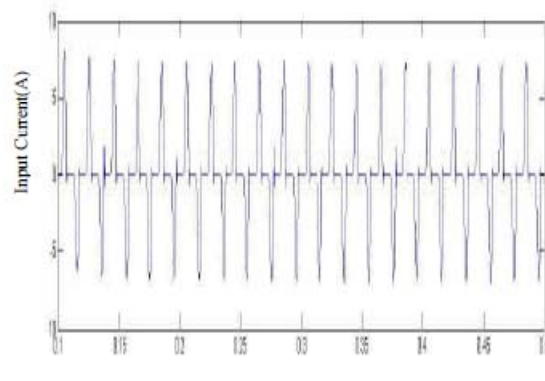


Fig. (10) Input Current Time (ms)

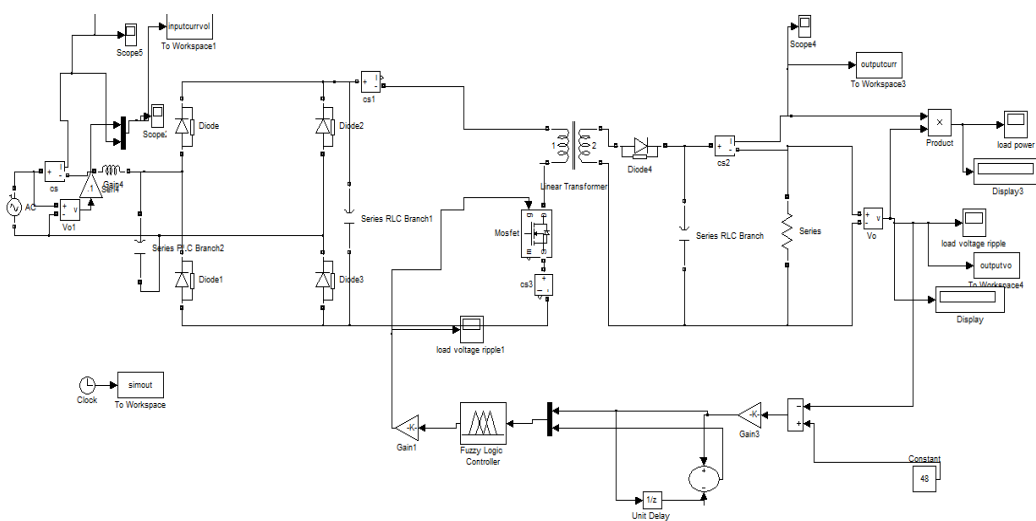


Fig. 11 : Simulink Model of AC to DC Flyback Converter with Fuzzy Controller in MATLAB

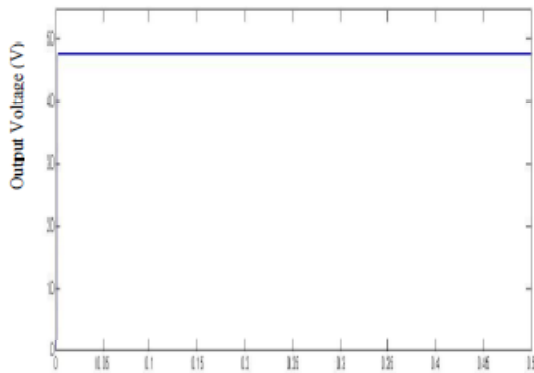


Fig. (12) Output Voltage Time (ms)

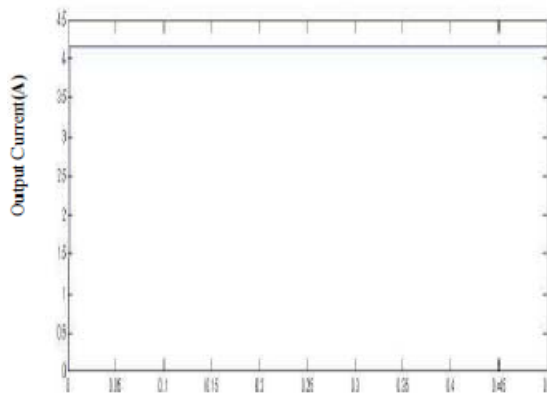


Fig. (13) Output Current Time (ms)

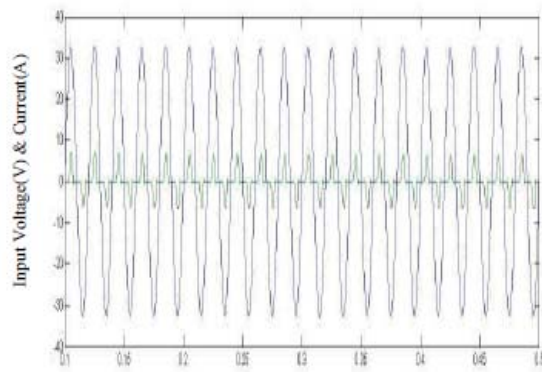


Fig. (14) Input Voltage & Current Time (ms)

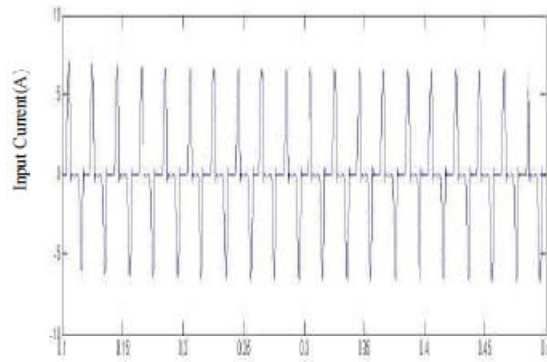


Fig. (15) Input Current Time(ms)

VII. CONCLUSION

In this paper Flyback Converter when PID based controller is used the Output ripple voltage is 3V and the Output ripple current is 1A. Where as by using FUZZY controller, the Output ripple voltage is 0.2V and the Output ripple current 0.1A. The input power factor is 0.707 for Flyback Converter. Hence we can conclude that the fuzzy controller is able to achieve faster transient response, less Peak overshoot, better rejection of disturbances and is less dependence on the operating point of the converter. If we want to improve input power factor, we can use integrated converters.

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