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An Intelligent Theory for Switch Mode Flyback Converter

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***Abstract*- In this paper presents the intelligent theory is control the non-linear behavior of the flyback converter with voltage mode control. The flyback DC-DC converter is operating ~170V 50Hz ac supply providing regulated output voltage 42V DC. Fuzzy logic controller covers a wider range of operating conditions, and they are design in natural language terms, which are based on general knowledge of the plant, it does neither require a precise mathematical modelling of the system nor complex computation. Fuzzy control rules are regulates the output of the flyback converter.The non-linear controller fuzzy logic controller (FLC) provides improved performances in terms of overshoot limitation and sensitivity to parameter variations in dynamic condition. To show the performance variations of the converters output with the fuzzy logic controller, flyback converter is simulated using MATLAB/SIMULINK.**

Keywords— Component: Fuzzy logic controller, flyback converter, voltage mode control,

I. INTRODUCTION

Efficient conversion of electrical power is becoming a primary concern to companies and to society as a whole. Switching power supplies offer not only higher efficiencies70 to 90 present but also offer greater flexibility to the designer. A switch mode flyback converter due to minimum number of semiconductor and magnetic components, are widely adopted for off-line low-cost power supplies. The flyback converter provides the isolation and short circuit protection by a single switch [1][2][3].

The causes of instabilities in flyback converter disclose the non-linearity include the variable structure due to the saturating inductance, voltage clamping, single switching period etc[4][5]. Fuzzy systems has a vagueness, incomplete, linguistically described, or even inconsistent which is applicable on the advance control, adaptive control, robust control as well as non-linear control system[6][7]. An un-predictive theory is offered by the fuzzy logic control (FLC), which does neither require a defined mathematical modelling of the system nor Complex computations.

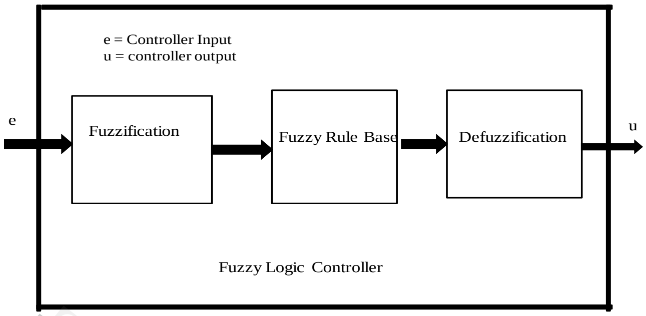

Fig.1. General Structure of a fuzzy logic controller

The majority of fuzzy logic control systems are knowledge-based systems in that either their fuzzy models or their fuzzy logic controllers are described by fuzzy IF-THEN rules, which have to be established based on experts knowledge about the systems, controllers, performance, etc. Fuzzy logic controller (FLC) consists of three basic portions-(a) the fuzzification unit at the input terminal,(b) the inference system built on the fuzzy logic control rule base in the core, and (c) the defuzzification unit at the output terminal, as shown in figure 1.Thus, control design is simple, since it is only based on linguistic rules of the type: "*if the output voltage error is positive and its rate of change is negative, then reduce slightly the duty-cycle*", and so on[8][9]. This approach lies on the basic physical properties of the systems and it is potentially able to extend control capability even to those operating conditions where linear control techniques fail, i.e. large-signal dynamics and large parameter variations [10].

II. BASICS OF FUZZY LOGIC CONTROLLERS

The fuzzy logic control is a new addition to non-linear control theory. The use of fuzzy logic control method in power electronics [zadeh 1994] has been increased in the last decades based on its simplicity design. Fuzzy logic control (FLC) is a new addition to control theory, which is one of the most successful applications of, fuzzy set theory. Fuzzy logic is a very useful device to treat nonlinear control phenomena and quantities in a logical way or the linguistic variables. Its design philosophy deviates from all the previous methods by accommodating expert knowledge in controller design. Its major features are it does not need any mathematical model and it will greatly reduce the development cost, takes less time and needs less data storage in the form of membership functions and rules. Fuzzy logic controller is adaptive in nature and can also exhibit increased reliability, robustness in the face of changing circuit parameters, saturation effects and external disturbances and so on[11][12].

The basic configuration of a fuzzy logic controller (FLC) is represented in fig.2 and comprises four principal components:

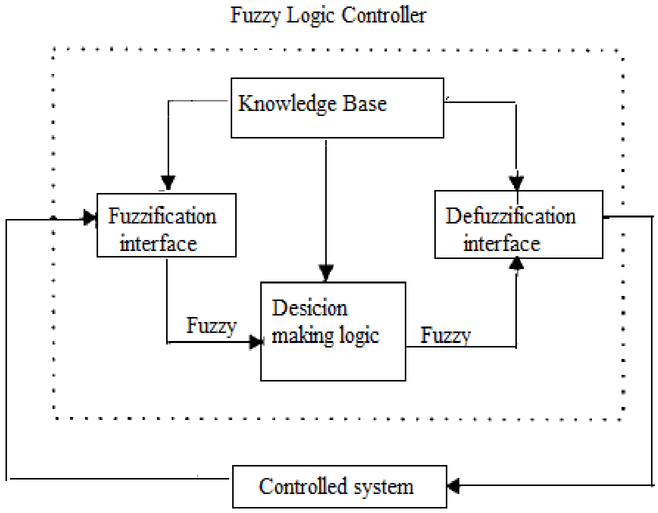

Fig.2. Basic configuration of fuzzy logic controller(FLC)

(a) Fuzzification

Fuzzification interface is converts input data into suitable linguistic values. The first step in the design of a fuzzy logic controller is to define membership functions for the inputs. Seven fuzzy levels or sets are chosen and defined by the following library of fuzzy-set values for the error e and change in error ce as shown in the fig.3. Each variables control has been divided into five partitions. They are as follows-

NB negative big; NM negative medium; NS negative small; ZE zero equal; PS positive small; PM positive medium; PB positive big.

The number of fuzzy levels is not fixed and depends on the input resolution needed in an application. The larger the number of fuzzy levels, the higher is the input resolution. The fuzzy controller utilizes triangular membership functions on the controller input.

The triangular membership function is chosen due to its simplicity as shown in the fig.4.

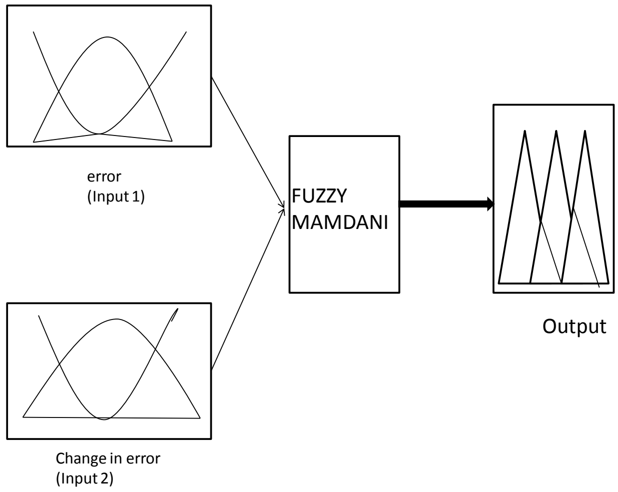

Fig.3. Membership functions for error (e) and change in error(ce).

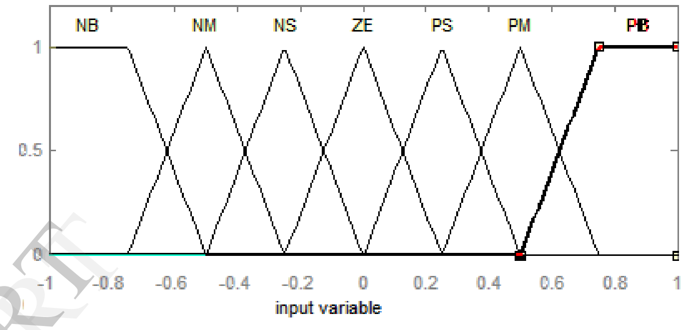

Fig.4. Membership functions of the input linguistic variables

(b) Rule Base or Decision-making

A knowledge base or rule base is consists of a data base with the necessary linguistic definitions and control rule set. Fuzzy control rules are based on the Mamdani rule based system. Decision making logic which, simulating a human decision process, infers the fuzzy control action from the knowledge of the control rules and the linguistic variable definitions;

The control rules that associate the fuzzy output to the fuzzy inputs for the dc–dc converter are derived from general knowledge of the system behaviour is tabulated in Table I as shown by the fig.5.

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 in error (ce) and output respectively. Error (e), change in error (ce) and output represent degree of membership. The derivation of the fuzzy control rules is heuristic in nature and based on the following criteria -

1) When the output of the converter is far from the set point, the change of duty cycle must be large so as to bring the output to the set point quickly.

	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

Fig.5. Fuzzy control rules

2) When the output of the converter is approaching the set point, a small change of duty cycle is necessary.
3) When the output of the converter is near the set point and is approaching it rapidly, the duty cycle must be kept constant so as to prevent overshoot.
4) When the set point is reached and the output is still changing, the duty cycle must be changed a little bit to prevent the output from moving away.
5) When the set point is reached and the output is steady, the duty cycle remains unchanged.
6) When the output is above the set point, the sign of the change of duty cycle must be negative, and vice versa

(c) Inference Mechanism
The results of the inference mechanism include the fuzzy relation. The max-min composition has become the best known and the most frequently used.

Max-min composition [R_1 (max-min) R_2]

$R_1 \circ R_2 = \{[(x, z), \max_y \{\min\{\mu_{R1}(x,y), \mu_{R2}(y,z)\}\}]\ x \in X, y \in Y, z \in Z\}$ (1)

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.

(d) De-fuzziffication
Conservation of the fuzzy to crisp or non-fuzzy output is defined as De-fuzzification. A de-fuzzification interface yields a non fuzzy control action from an inferred fuzzy control action.
In the de-fuzzification operation a logical sum of the inference result from each of the four rules is performed. This logical sum is the fuzzy representation of the change in duty cycle (output).

III. VOLTAGE MODE CONTROLLER

As for the control technique, two approaches, voltage-mode control and current-mode control, are applicable in the DC-DC flyback converter.

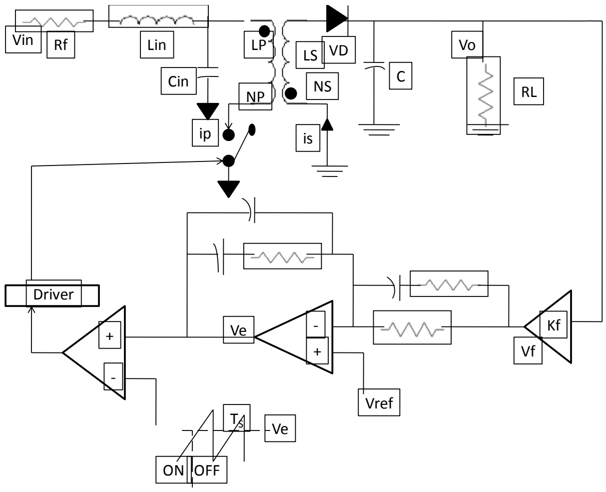

Fig.6.Flyback converter with voltage mode control

General schematic diagram for controlled duty cycle in voltage mode controlled flyback converter as shown in fig 6. In this voltage mode control scheme the converter output voltage is sensed and subtracted from an external reference voltage (Vref) in an error amplifier. The amplifier produces a control voltage that is compare to constant amplitude saw-tooth waveform. The comparator generates a PWM signal that is fed to drivers or duty cycle 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 [13][14][15][16].

Mode-1
Basic operation of flyback converter is divided on main two modes. In mode 1 show by the fig.7, when the switch (MOSFET) is turned on, the primary current i_1 flows, while the diode is reverse biased preventing a flow of secondary current i_2. During this MOSFET's turn on period, energy is stored in the transformer with a load current being supplied by the output capacitor.

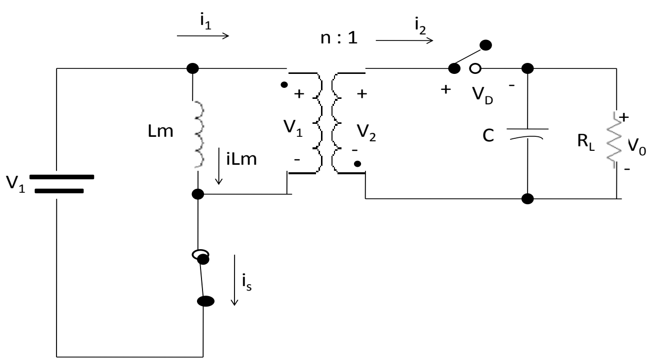

Fig.7.Equivalent circuit diagram of flyback converter for Mode 1

The diode current i_D,

$$i_D = i_2 = 0 \qquad (2)$$

The primary current $I_1 = i_2 / -n$ (3)

The voltage across the magnetizing inductance L_m show in fig.8

$$V_{LM} = V_1 = L_m.\left(\frac{d}{dt} iLM\right) \qquad (4)$$

At time t=0, $I_{LM}(0)$ is the initial current in the magnetizing inductance .The peak-to peak value of the ripple current through the magnetizing inductance L_m is

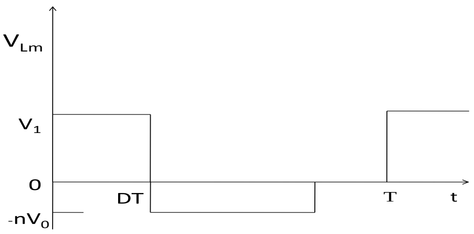

Fig.8.Voltage across the switch

$$\Delta I_{Lm} = \frac{V1DT}{Lm} = \frac{V1D}{fs.Lm} \qquad (5)$$

the transfer function of the flyback converter is

$$Mv_{DC} = \frac{V0}{V1} = \frac{I0}{I1} = \frac{D}{n(1-D)} \qquad (6)$$

Mode 2

In mode 2 show by the fig.9, the switch (MOSFET) is tuned off, the primary current stop to conduct. The polarity of secondary voltage is become too negative. The diode is now forward biased enabling a flow of secondary current. During this turn off period, energy stored in the transformer is released to the output capacitor and load.

The secondary voltage

$$v_2 = V_O \qquad (7)$$

$$V_1 = -n\, v_2 = -nV_0 \qquad (8)$$

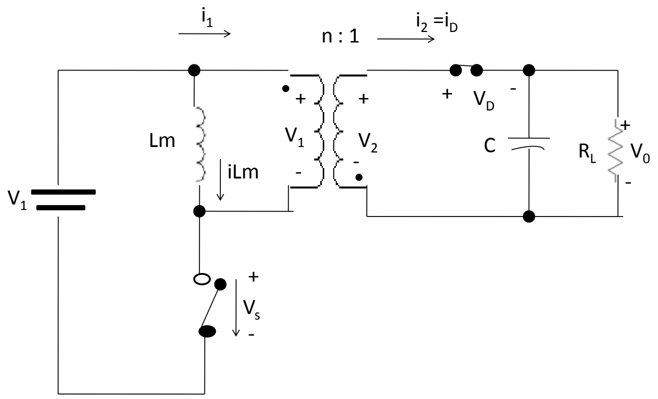

Fig.9.Equivalent circuit of flyback converter in mode2

The current through the magnetizing inductance is show in fig.10

$$I_{Lm} = -n\frac{V0}{Lm}(t\text{-}DT) + \frac{V1D}{fsLm} + i_{Lm}(0) \qquad (9)$$

The converter's main energy storage inductor may operate in two modes: DCM and CCM.

At CCM/ DCM boundary the minimum value of the magnetizing inductance

$$L_m(min) = \frac{(1-Dmin)^2 n^2 RLmax}{2fs} \qquad (10)$$

$$Lm(min) = \frac{n^2 Vo\,(1-Dmin)^2}{2fs.Iomin} \qquad (11)$$

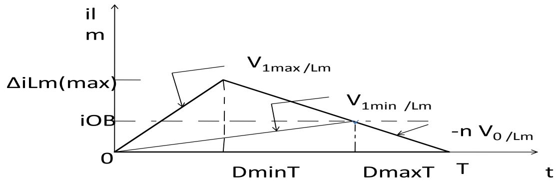

Fig.10. Waveform of the current through the magnetizing inductance

The energy transferred from the input dc voltage source V_1 to the magnetizing inductance during one cycle for the boundary case is

$$W_{OB} = \frac{Lm(max)\Delta iLm(max)2}{2} \qquad (12)$$

The total power output at the boundary

$$P_{OB} = \frac{WOB}{T} = f_S W_{OB} = \frac{fs.Lmmax\ \Delta i2Lm(min)}{2} \qquad (13)$$

IV. DESIGN OF FUZZY LOGIC CONTROLLER FOR DC-DC CONVERTERS

In DC-DC converters fuzzy logic controller has applied to the regulation of load voltage and performance the robustness due to its non – linear dynamic characteristics of the DC-DC converter.

Design of fuzzy logic controllers is based on expert knowledge of the plant instead of a precise mathematical model. There are two inputs inside the fuzzy logic controller for the flyback converters. The first input is the error in the output voltage given by equation (14), where ADC[k] is the converted digital value of the k_{th} sample of the output voltage and Ref is the digital value corresponding to the desired output voltage. The second input is the difference between successive errors and is given by the equation-

$$e[k] = Ref - ADC[k] \qquad (14)$$

$$ce[k] = e[k] - e[k-1] \qquad (15)$$

The two inputs are multiplied by the scaling factors g_0 and g_1, respectively, and then fed into the fuzzy logic controller. The output of the fuzzy controller is the change in duty cycle $\Delta d[k]$, which is scaled by a linear gain h. The scaling factors g_0, g_1, and h can be tuned to obtain a satisfactory response.

Fig.11 show the general block diagram for fuzzy logic controlled flyback converter in which control for DC-DC flyback converter is made from 2 inputs and 1 output variables, which are error and change in error as input variables, and the duty cycle as output variable.

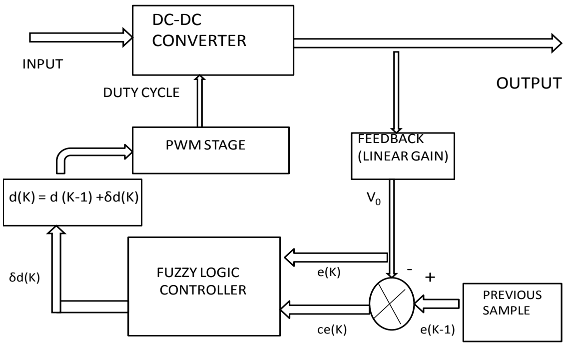

Fig.11. Schematic diagram for fuzzy controlled DC-DC converter

The fuzzy logic controller works as an error amplifier. The output voltage V_0 is feedback and sum with the reference voltage V_{ref}, which gives the error in voltage (input 1) for controller. The second input change in error is the sum of the error signal and each sampling periods. The integrator is used to eliminate the steady state error.
The output of the fuzzy logic controller is compare with the saw-tooth signals for generate the controlled duty cycle for switch (MOSFET) in the flyback converter. For the simulation purpose the model parameters are given in table 1. The simulation circuit diagram are shown in the fig 12

SIMULATED CIRCUIT PARAMETERTABLE 1

Sr.No.	Parameter	Ranges
a)	Input Voltage	90-230V
b)	Output Voltage	41V
c)	Load Resistance	10 ohms
d)	Line Frequency	50 hertz
e)	Total Output Power	160W(<200W)
f)	Switching Frequency	200KHz

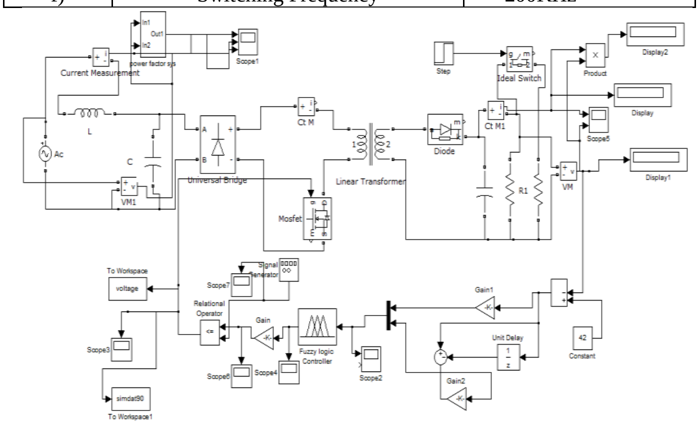

Fig.12 Simulation circuit diagram for fuzzy logic controlled flyback converter.

V. SIMULATION RESULTS

The simulation is closed loop flyback converter controlled with fuzzy controller is done for 5 second. The non- linear fuzzy controller gains g_0,g_1 and h are obtained by the heat and trial method.

(a) Simulation response for input power factor correction.
The advantage of switch mode power supply (SMPS) is higher efficiency with high power factor. In SMPS a diode rectifier effects the ac/dc conversion, while the controller operates the switch in such a way to properly shape the input current i_g according to its reference. An ideal power factor corrector should imitate a resistor on the supply side while maintaining a fairly regulated output voltage.

From equation (2, 3), obviously, the sinusoidal input current i_s is inherently generated, and its current amplitude I_s =Vs/wL is proportional to the controllable phase φ without sensing current and current loop. Moreover, the sinusoidal input current i_s is in phase with the input voltage V_s. The simulated results as shown by the fig taken on the input side, which shows the input current waveform i_s , is less distorted and as close as possible with the input voltage waveform V_s. The simulated waveform shows fig.13 the input side power factor nearly 1.

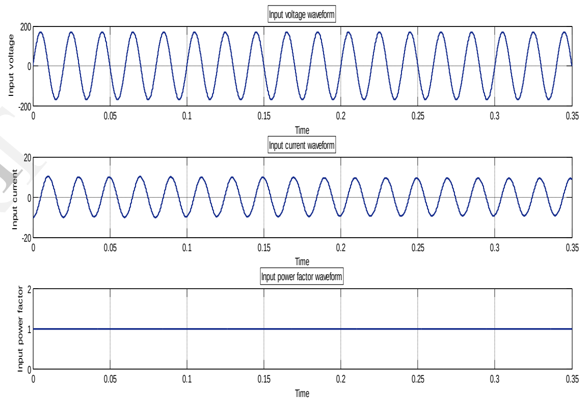

Fig.13. simulation response for input power factor

(b) Simulation response for transient condition of fuzzy logic controlled flyback converter
For the circuit parameters in Table 1 the simulated waveforms are obtained in fig.14, the output current and voltage waveform. The output voltage and output current of the system are 42V and 3.9A respectively given by the fuzzy controlled flyback converter. The transient responses of the fuzzy controlled flyback converter are listed in Table 2.

TABLE 2

Sr.No.	Parameters	values
a)	Rise Time	0.45 Sec.
b)	Peak Time	0.65 Sec.
c)	Overshoot	0.0124%
d)	Settling Time	0.9Sec.

(c) Simulation response for dynamic condition of the fuzzy logic controlled flyback converter
The proposed non-linear fuzzy logic controlled flyback converter is evaluating using MATLAB/ Simulink is shown in fig.15. Dynamic condition of fuzzy logic controlled flyback converter where the load resistance is suddenly

changed parallel with the another resistance from 10.5 Ω (W) to10.5||200 Ω at t= 0.8 second. The response of the output voltage has a little drop at t=0.08 second and after some time it's attain a finale output voltage value.

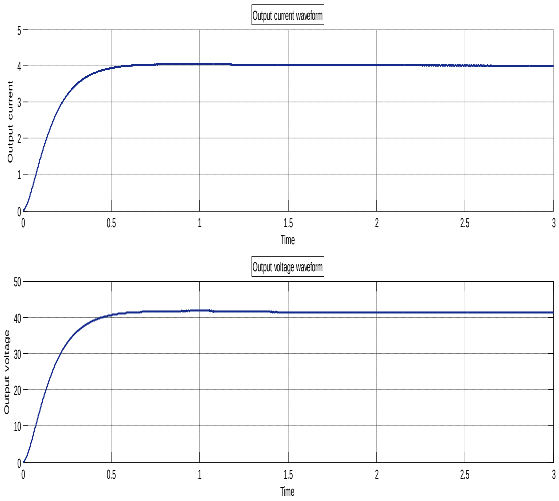

Fig.14.Simulation response for transient condition in fuzzy controlled flyback converter

In order to support sufficient power to regulate the output voltage, the input current magnitude is increased from 3.8A to near 4.2A by the controller.

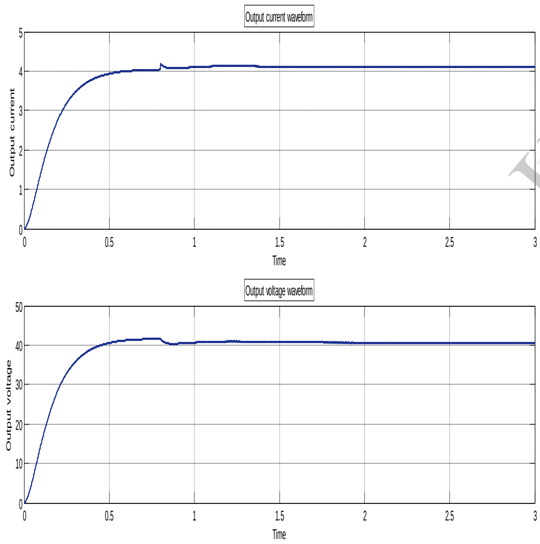

Fig.15. Simulation response for dynamic condition in fuzzy controlled flyback converter

From this case, we can find that the input current i_s is always in phase with the input voltage v_s under transient response. Consequently, the controller can keep good performance under the condition of load change. During this test the reference voltage of the converter is 42V.

VI. CONCLUSION

The non-linear controller fuzzy logic controller(FLC) in the flyback converter has presented with a very useful device to treat non-linear behaviour and quantities in a logical ways of the flyback converter. Its design methodology is very simple and doesn't need any type of mathematical model.
Fuzzy logic controller produces less voltage deviation. Less overshoot and sensitive to parameter variation and low cost makes fuzzy logic control results in better transient and dynamic performance. FLC can also be applied to many converter topologies. Fuzzy logic controller (FLC) has advantages of faster response with higher accuracy.

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