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Fuzzy Controlled Multiple Output Dc to Dc Flyback Converter with Output Voltage Regulation

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***Abstract:** The aim of this paper is to design and closed loop control implementation of a DC to DC Flyback converter with multiple output features. DC-DC Conversion technology is the major subject area in the field of power electronics engineering and drives and has been under development form six decades. Most of the advance systems like telecommunication and computer systems use the single output DC-DC Converter for different levels of voltage in the same system, which limits the efficiency, power density and increases the cost of the whole system. To achieve the features like high efficiency and high density for advance systems Multiple Output DC-DC Converter (MODC) are gathering much attention, and most of the research work is going to get the regulated multiple outputs, for different application like computer, electric vehicles, aircrafts etc. A MATLAB/Simulink model of a Multiple Output Flyback Converter (MOFC) is developed to get the regulated multiple output voltage. Two different control techniques have been employed such as Proportional Integral Derivative Control (PIDC) and Fuzzy Logic Control (FLC), to achieve the same for normal and disturbances cases and its performance is then estimated in terms of various parameters like Rise Time (Tr), Settling Time (Ts) and Overshoot (OS). The comparative results clearly reveal the better response of the proposed approach.*

***Keywords:** Flyback converter, Multiple Output, FLC, PIDC.*

I. INTRODUCTION

In recent years, telecommunication, and computer system have experienced fast growth. This advance system requires distributed supplies with standard power levels with features like, high efficiency, and high power density, unfortunately standard source voltage may not match the levels required by the system [1]. Therefore the DC-DC converters are getting more and more use in different application, to fulfill their required voltage and power levels [2-3]. In modern electrical and electronic technology, voltage scheduling with Multiple Output Voltage draw great interests, because Multiple Output Voltage is the most effective way to get the different power levels with reduced power consumption in the circuit, improved cross regulation [4-5] and high efficiency especially for electronic circuit. In a portable device, such as Cell phone, PM3 player, PDA, or Laptop, and other area like space craft, electric vehicle and different DC supply voltage levels suitable for different components are needed [6].The basic block diagram of a Laptop Computer power supply system is shown in Fig.1 [7]. In the most recent technology of Organic Light-Emitting Diode (OLED) display, Active-matrix(AM) OLED panels, need a different sophisticated voltage supply for each color (Red, Green, or Blue) to optimize display efficiency and display quality with brightness, contrast, and vividness [8].

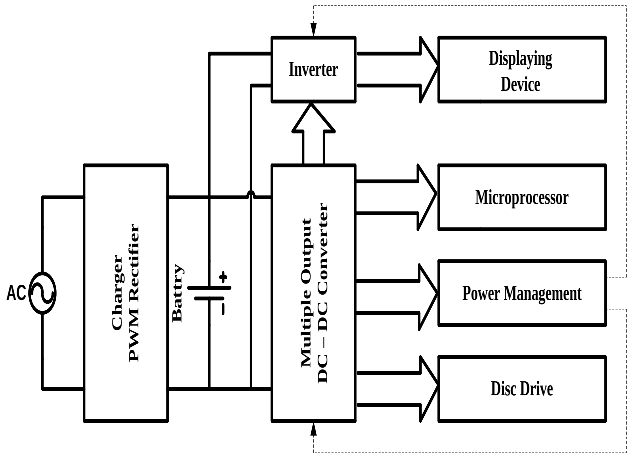

Fig.1 Block Diagram of a Laptop Computer power supply system

All of the above mentioned typical needs from real applications pose a challenge to DC-DC switching converter designers: from a single input power supply with multiple outputs with different voltage levels fulfilling above mentioned features [9-10]. Converters utilizing a single primary power stage and generating more than one isolated output voltage are called MODC. The basic block diagram of MODC circuit is shown in Fig.2, in that a dc supply is connected with a high frequency multi winding transformer having single primary winding N_p and multiple secondary windings N_{s1}, N_{s2} …. N_{sn} connected with respective output rectifier, filter and load. These circuits provide isolation and several output voltages using one high frequency isolation transformer as opposed to individual power modules for each output as it is frequently done in distributed power systems. According to the required voltage and power levels the different topologies of multiple output converters are to be used which are given below.

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There are several MODC topologies:

1. Forward converter
2. Flyback Converter
3. Push-pull Converter
4. Full-bridge Converter

In all non-isolated converter like Buck, Boost, and Buck-Boost, the return end of the regulated output voltage is dc common with the return end of the dc point. In all these converters input and output are not isolated; hence multiple outputs are not possible [11]. All these (Forward, Flyback, Flyback, Full-bridge) converter topologies delivers their power to the loads via a transformer, hence output voltage returns are dc-isolated from input return and with multiple transformer secondary, hence multiple dc output voltages are possible. Comparing with all the above isolated topologies Flyback topology requires less circuit component and provides simple operating principle, hence in this work MOFC is proposed [12].

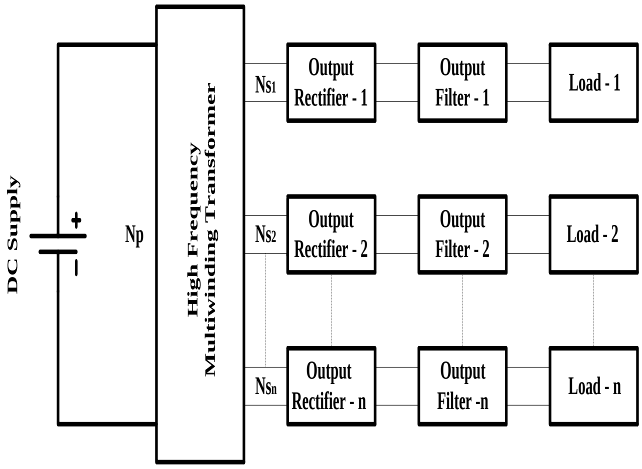

Fig.2 Basic block diagram of MODC

II. MULTIPLE OUTPUT FLYBACK CONVERTER

The circuit shown in Fig.3 shows the MOFC, which is basically a DC-DC Buck-Boost converter with the addition of a transformer for output voltage isolation and scaling. The detail circuit description and operating principle of MOFC are to be discussed below:

A. Circuit Description

The circuit configuration for the MOFC with k output where k =1,2,3,4,……..n, is shown in fig. 3. It consist transformer with primary turn N_p and secondary turn N_{sk} for electrical isolation and voltage scaling of k[th] outputs. N_{sk}, where k=1, is secondary winding corresponding to main output, and others secondary winding $N_{s(k+1)}$, where k= 1, is k=1,2,3,…..n, are corresponds the auxiliary outputs, Flyback transformer do not carry current simultaneously and in this sense Flyback transformer works differently from a normal transformer. Since primary and secondary windings of the Flyback transformer do not conduct simultaneously they are more like two magnetically coupled inductors and it may be more appropriate to call the Flyback transformer as inductor transformer.

B. Operating Principle

The equivalent circuit and steady state waveform of MOFC is shown in fig 4(a),(b) and Fig. 5 respectively. For the analysis of MODC the following assumptions are made.

1. Input and output voltage V_{in} and V_{ok} are constant.
2. The load current I_{ok} are constant.
3. L_{ok} and C_{ok} are ideal

Mode 1: Switch SW is ON ($0 \leq t \leq DT$)

When switch SW 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_1' 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 SW, primary winding is able to carry current but current in the secondary winding is blocked due to the

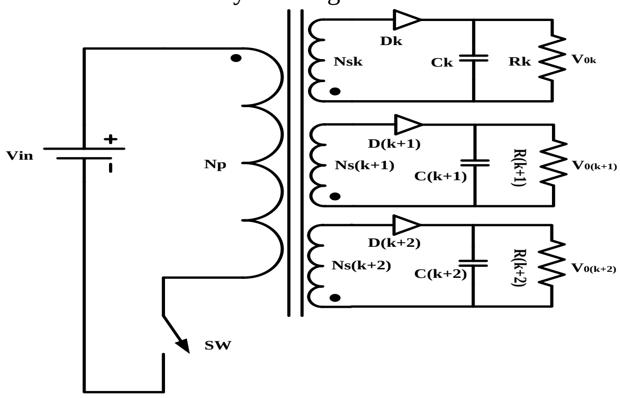

Fig.3 Configuration of MOFC

Reverse biased diode. The flux established in the transformer core and linking the windings is entirely due to the primary winding current. Stored charge in filter capacitor cause of load current in this mode. Fig. 4(a) and Fig.5 shows the active current path and different voltage waveforms of mode 1 operation respectively.

The converter equation of this mode are given below

$$V_p = V_{in}$$

(1)

$$i_m(t) = \frac{V_{in}}{L_m} t + I_{m\min}$$

(2)

At t = DT, $I_m(t) = I_{\max} = \dfrac{V_{in}}{L_m} DT + I_{m\min}$

(3)

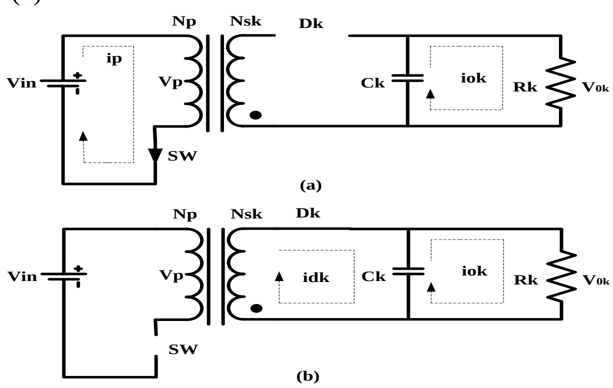

Fig.4 Equivalent circuit of Flyback converter in Mode 1and Mode 2 respectively

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Mode 2: Switch SW is OFF (DT ≤ t ≤ T)

When switch SW is turned off, the primary winding current path is open 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.4(b) and Fig.5 shows the active current path and different voltage and current waveforms of mode 2 operation. The converter equation of this mode is given below:

$$V_p = -\frac{N_p}{N_{sk}} V_{0k} \quad (4)$$

$$i_m(t) = \frac{\left(\frac{N_p}{N_{sk}}\right) V_{0k}}{L_m}(t - DT) + I_{m\min} \quad (5)$$

At t = T, $I_m(t) = I_{m\min} = \frac{\left(\frac{N_p}{N_{sk}}\right) V_{0k}}{L_m}(1-D)T + I_{m\max}$ (6)

As we know that the average voltage across inductor in one cycle is zero, we get

$$V_{in}DT = \frac{N_p}{N_{sk}} V_{0k}(1-D)T \quad (7)$$

Or Voltage Gain = $\frac{V_{0k}}{V_{in}} = \frac{N_{sk}}{N_p}\frac{D}{(1-D)}$ (8)

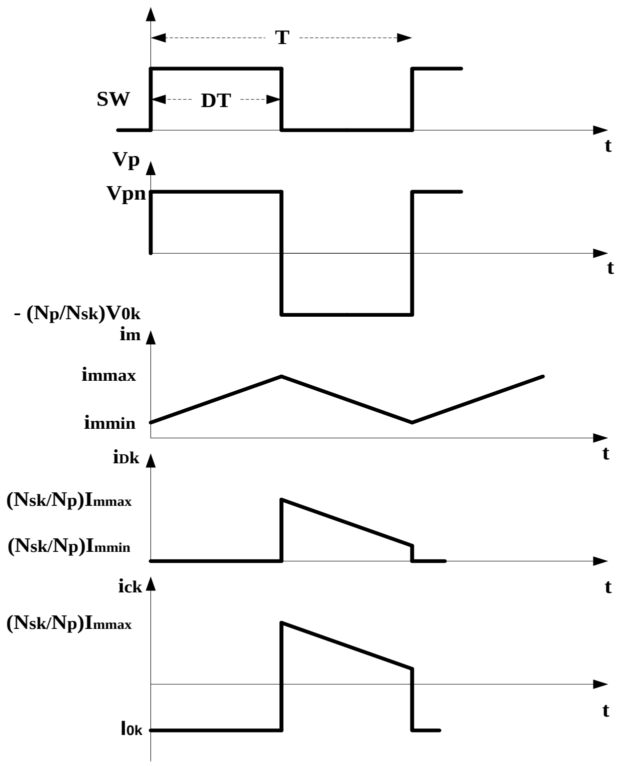

Fig.5 Steady state waveform of MOFC

III. DESIGN OF MOFC

A MOFC is shown in Fig.3 the design of different parameters of that converter is as follows.

A. Transformer Turns Ratio.

The Transformer winding turn ratio is a most important design factor of any isolated converter. In Flyback converter, transformer works differently from the normal transformer, it is more likely to work as coupled inductor, which stores energy during turn-on time and transferred to the output side during the turn-off period. The primary to secondary turn ratio of the transformer must satisfy the following condition to get the desired output voltage.

$$\frac{N_{sk}}{N_p} = \frac{V_{in} * D}{(V_{0k} + V_D)(1-D)} \quad (9)$$

B. Output Filter

Filter capacitor is important selection parameter, to keep output voltage ripple less, means constant output voltage, the output filter capacitor can be design as follows:

Charge stored in output capacitor

$$Q = C_k * V_{0k} \quad (10)$$

Change in stored charge

$$\Delta Q = C_k * \Delta V_k \quad (11)$$

Where ΔV_{0k} is the voltage ripple

Hence

$$\Delta Q = C_k * \Delta V_{0k} = I_{0k} * DT = \frac{V_{0k}}{R_k} * DT \quad (12)$$

$$C_k = \frac{V_{0k} * D}{R_k * L_k * f} \quad (13)$$

Eq.(13) gives the optimum value of filter capacitor.

IV. CLOSED LOOP CONTROLLED MODC

A negative feedback is employed to maintain voltage regulation regardless of disturbance in load current or supply voltage or variation in component values of converter. The duty cycle is varied in the feedback loop to control for their variation. A typical block diagram of switching regulator is as shown in Fig. 6.

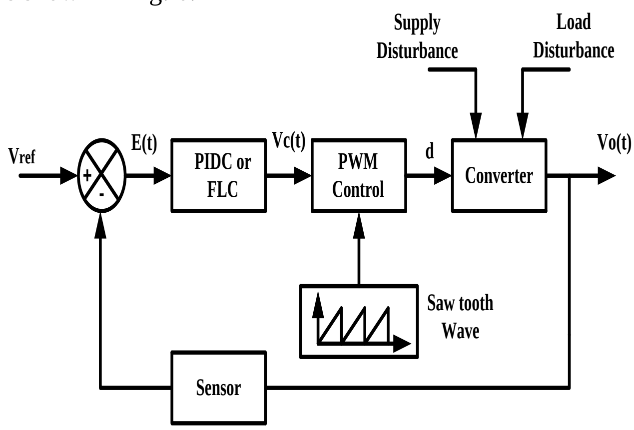

Fig.6 Block diagram of closed loop control converter

A. PIDC for Close Loop Voltage Regulation

The name itself Proportional-Integral-Derivative Controller is a sort of control circle component received in nonstop adjusted activity of control.

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A PIDC over and again ascertain the mistake in the middle of a Set Point (SP) esteem and estimated Process Value (PV) and get a redress as needs be in PID base. Progressively activity it as needs be gives a precise and individual difference in redress to a control work. For instance heater temperature control that it applies a subsidiary term to adequately address the blunder in spite of a gigantic change

B. FLC for Close Loop Voltage Regulation

The fundamental square outline of the proposed FLC for output voltage regulation MOFC is appeared in Fig.7. Any item has a level of participation which shifts from 0 to 1 in the fuzzy set hypothesis, which makes fuzzy rationale to deal with all circumstances in a characteristic manner. The state of participation capacities can likewise be trapezoidal or Gaussian and so on relying upon the applications and can be balanced or hilter kilter. The MOFC voltage error is characterized in linguistic variables, for example, Positive Big (PB), Negative Big (NB), Positive Medium (PM), Negative Medium (NM), Positive Small (PS), Negative Small (NS),Zero (ZE), where every factor is characterized by a bit by bit shifting triangular membership function. For errror (e) and change in errror (de) seven fuzzy sets are picked. For a specific application relying upon the information goals the quantity of fuzzy levels is chosen which in not fixed. Higher will be the info goals more must be the quantity of fuzzy levels.

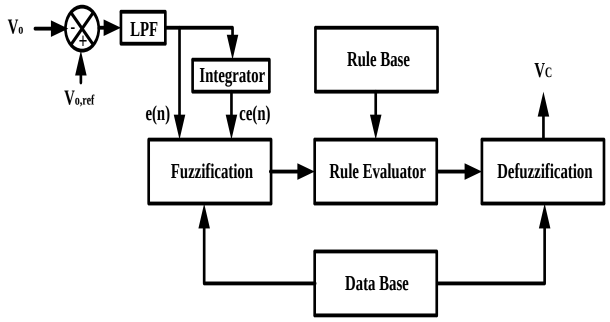

Fig.7. Basic block diagram of FLC

Each input is assigned a membership function µ which isn't quantizes in the traditional sense to each fuzzy set. To lessen the trouble in computation here triangular fuzzy set qualities are utilized we may likewise utilized chime formed or trapezoidal fuzzy set contingent upon the application. For n number of variable the fuzzy principles are n dimensional. The total of rules is known as rule R. FIS editor alters the info and yield factors, which are e, de and yield. Subsequent to altering we need to plan the enrolment work for every factor. The last advance includes of composing rules in rule manager utilizing the standard given in Table I

Table - I. Fuzzy Rules for Closed Loop Control of MOFC

e\de	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NE	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	PM	PB	PB	PB

V. RESULT AND DISCUSSION

To investigate the performance of the proposed System a simulink model of a Three Output Flyback Converter (TOFC) is developed as shown in Fig.8.

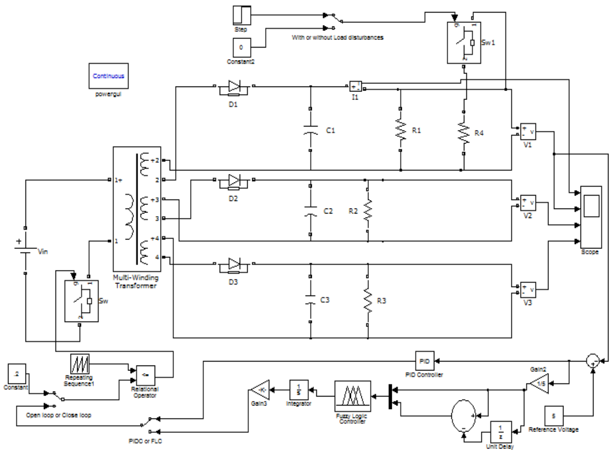

Fig.8. Simulink Model of TOFC

As discussed in section III we designed the TOFC and all the designed parameter used in simulation is given in Table II.

Table - II Parameter Selected for TOFC

Input Parameter			
Input Supply Voltage (V_{in})	50V	**Transformer ratio**	
Switching Frequency (f)	40kHz	$N_{s1}/N_p = 4:16$	
Magnetizing Inductance (L_m)	0.017 mH	$N_{s2}/N_p=12:16$	
		$N_{s3}/N_p=12:16$	
Output Parameter			
Parameter	**Main Output**	**Auxiliary - 1 Output**	**Auxiliary - 2 Output**
Vo (Volt.)	5	12	12
Io (Amp)	5	2	3
Ro (Ω)	1	6	4
Co (µF)	2080	500	750

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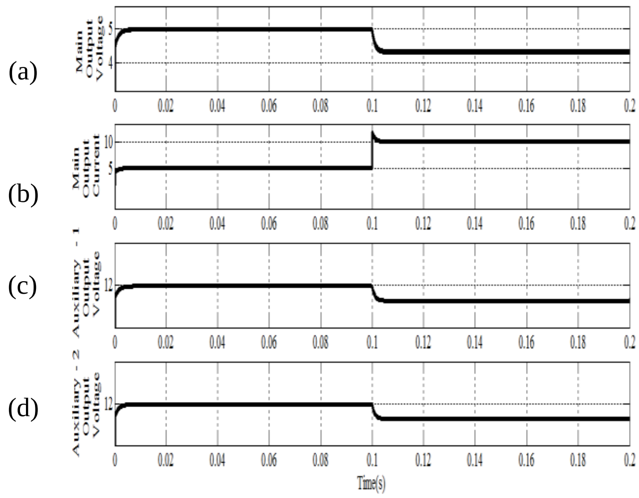

Fig. 9. Simulation results of TOFC in open loop

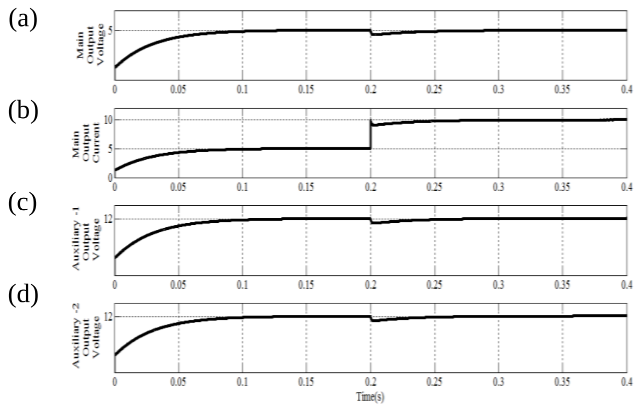

Fig.10. Simulation results of TOFC using PIDC

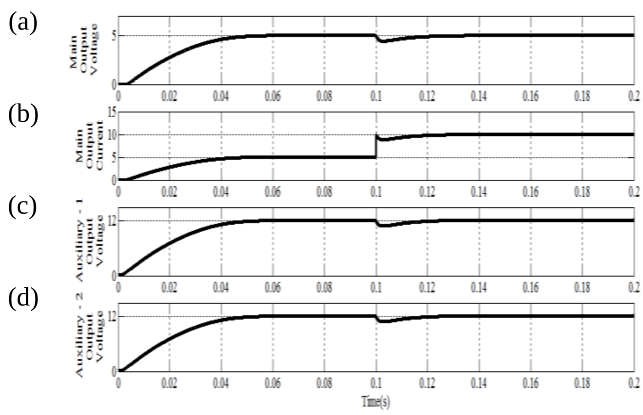

Fig.11. Simulation results of TOFC using FLC

The system performance is investigated in three cases. Case:1 When TOFC is controlled in open-loop (i.e. without PIDC or FLC). Case:2 When TOFC is controlled using PIDC to get the regulated multiple voltage. Case:3 When TOFC is controlled using FLC to get the regulated multiple voltage. Simulation results of TOFC in open loop are shown in Fig. 9(a-d). When a load change is applied at t = 0.1 sec, it can be observed that the three output voltages are not regulated at 5V, 12V, 12V respectively for main output, auxiliary - 1 and auxiliary - 2 output voltage. To upgrade the efficacy of the output voltage PIDC or FLC is used in the feedback loop. Fig. 10(a-d) and Fig. 11(a-d) shows the simulation results of TOFC are controlled using PIDC and FLC respectively. From Fig.10 and Fig.11 it is can be observed that in spite of load disturbances all the three output voltages are regulated with their respective reference value. Various performance parameter obtained in simulation are as in TABLE III for comparison.

TABLE - III Performance Parameters of TOFC Under Different Condition

Performance Index / *Different Condition*		Rise Time (msec)	Setteling Time (msec)	% Overshoot
TOFC in Open Loop	**Main Output**	40	50	5
	Auxiliary - 1 Output	50	60	6.5
	Auxiliary - 2 Output	30	40	5.2
TOFC using PIDC	**Main Output**	45	49	4.1
	Auxiliary - 1 Output	43	48	5.2
	Auxiliary - 2 Output	43	50	5.3
TOFC using FLC	**Main Output**	18	20	2.1
	Auxiliary - 1 Output	18	21	3.2
	Auxiliary - 2 Output	19	21	2.2

VI. CONCLUSION

The design, modelling and simulation of TOFC used for multiple output purpose from a single DC input is considered in MATLAB/Simulink environment. The outcomes of the simulation work provided a improved parameters like Rise Time (Tr), Settling Time (Ts) and Overshoot (OS). Comparing with PIDC and FLC used in the output feedback loop, FLC gives better result in terms of Tr, Ts, OS. During dynamic conditions FLC gives a well regulated multiple voltage at the output. The prototype of the proposed TOFC converter can be developed, that would be attempted as a future work.

REFERENCES

1. A. Barrado, E.Olias, A. Lazaro, R. Vhquez, J. Pleite. “Multiple Output dc/dc Converters Based On PWM-Pulse Delay Control (PWM-PD)” , in *Proc. IEEE Power Electron. Spec. Conf.*, June 1999, pp.1141-1145.
2. J. Lee, D. Y. Chen, C. Jamerson. “Magamp Post regulators-Practical Design Considerations to allow Operation Under Extreme Loading Conditions” *IEEE Trans. Power Electronics*, vol.5,Jan.1990,pp.69-76
3. N. Barry, B. Daly “Coupled Magnetic Amplifiers in Forward Converter Topologies Noel Barry”, *IEEE Trans. Power Electronics*, vol.14,no.1,Jan.1999,pp.168-175.
4. G. Levin “Designing with a new Secondary Side Post Regulator (SSPR) PWM Controller for Multiple Output Power Supplies”, in *Proc. IEEE/APEC*-1995, pp.736-742.
5. W. Tang “A New Control Method for Synchronous-Switch Post Regulator” , in *Proc. IEEE/PESC*-2000, pp.408-411.
6. C. Ji, K. Mark Smith, Jr.Keyue M. Smedly and Ken King “Cross Regulation in Flyback Converters: Analytic Model and Solution” *IEEE Trans. Power Electronics*, vol.13, Sep 1998,pp.852-860.
7. Y. T. Chen, “The Overall Small-Signal Model of the Synchronous Switch Post regulator” *IEEE Trans. Power Electronics*, vol.16, Mar.2001,pp.231-239.
8. H. Matsuo “Comparison of Multiple-Output DC-DC Converters Using Cross Regulation” in *Proc. IEEE/PESC, 1979*, pp.169-185.

9. J. B.V.Reddy, G. Bhuvaneswari and Bhim Singh "A Single DC-DC Converter Based Multiple Output SMPS with Fully Regulated and Isolated Outputs" , *IEEE Annual INDICON Conf*, 2005 pp.585-589
10 P. Mattavelli, L. Rossetto, *G.* Spiazzi, P.Tenti "General-Purpose Fuzzy Controller for DCDC Converters", *APEC'95*,March-1995,vol-2,pp. 732-730.
11. N. Vazquez, H. Lopez, C. Hernandez, H. Calleja "Multiple-Output DC-to-DC based on the Flyback Converter" *IEEE International Conference on Power Electronics CIEP'08 2008*, pp.105-108.
12 L. K. Kaushik, M. K.Pathak, "An Improved Multiple Output Forward Converter Topology'. *International Conference on Advances in Power Electronics and Instrumentation Engineering-ACEEE(Springer)*'10.07-09Sep, 2010.Ref ID-PEIE-43

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