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Voltage Feed-Forward Controlled 75W Forward Converter with Type-2 Compensation and Protection Circuits

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***Abstract:** In recent years, DC-DC converters find many applications in low to medium power range. The isolated converters are used in medium power application such as military, electric vehicle (EV) and space industries since they provide isolation between input and output and protection from input side faults. These are made capable of providing a specified output voltage by managing the PWM pulses delivered to the switching device's gate. This paper presents use of voltage feed-forward method which helps in suppressing effect of input line harmonics and disturbances and gives regulated output voltage. The converter is operating at a switching frequency of 140 kHz and behaviour of switching device is not taken into consideration. The converter has protection circuits like over voltage protection (OVP), over current protection (OCP) on input and outputs, under voltage protection (UVP) which protects from abnormal operating condition. The design and simulation results of the feed-forward technique with type-2 compensation and protection circuits are discussed.*

***Keywords:** Forward Converter, Feed-Forward Method, Over Voltage Protection, Over Current Protection, Under Voltage Protection.*

I. INTRODUCTION

Switch mode power supplies have been used in applications where high efficiency and better reliability is of prime concern. The dc-dc converter often categorised into isolated and non-isolated. In isolated dc-dc converter forward topology is preferred when output power demand is in the range of 150-200W [2]. Though isolated dc-dc converters provide galvanic isolation between input and output, there are instances where it's required to provide protection against short circuit or over load current, output over voltage and input under voltages and these may be drawback for the converter operation. Hence this paper explains a very effective techniques to overcome these drawbacks. The voltage feed-forward method with type-2 compensation is explained as it does not depend on load variation; instead, it reacts to control signals that have been predefined. It is used to lessen the abrupt changes in the input line voltage fluctuations cause changes in output voltage, which provides improved regulation by adjusting the duty cycle in accordance with change in input voltage [3]. The other protection circuits like over current, over voltage and under voltage are simulated and results of the same are presented. The simulation is carried out using LTspice software.

II. VOLATGE FEED-FORWARD METHOD WITH TYPE-2 COMPENSATION

To have a stable closed loop converter with appropriate performance, a properly designed compensator is required. Hence type-2 compensation with voltage feed-forward method is used, which gives fast dynamic response against the input voltage variations. The following parameters are considered to design type-2 compensation.

$V_{in(min)}$ = 24; $V_{in(max)}$ 42.5; V_o = 6V/12A;F_{sw} = 140kHz; L_o = 30µH; Co =330µF; V_{ref} = 2.5V ; ESR=10mΩ:P_O =75W:**η**=65%

A. Design of Type-2 Compensation.

1) Calculation of poles and zeros of power supply

$$F_{LC} = \frac{1}{2*\pi*\sqrt{L*C}} \quad (1)$$

= 1.6 kHz

2) Zero caused by ESR of output capacitor

$$F_{ESR} = \frac{1}{2*\pi*ESR*C} \quad (2)$$

= 48.22 kHz

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3) Crossover frequency is chosen as $\frac{1}{10}th$ of the switching frequency

$$F_{co} = \frac{140*1000}{10} \tag{3}$$

$$= 14 \text{ kHz}$$

4) Pole and Zero of compensator

$$F_z = 0.75*F_{LC} \tag{4}$$

$$= 1.2 \text{ kHz.}$$

$$F_P = \frac{Fsw}{2}$$

$$= \frac{140*1000}{10} = 70 \text{ kHz.}$$

5) Calculation of compensation resistor R_{C1}

$$R_{C1} = \frac{Rf*Fesr*Vosc*Fco}{Vin*Flc} \tag{5}$$

$$= 1K\Omega.$$

6) Calculation of compensation capacitor C_{C1}

$$C_{C1} = \frac{1}{2*\pi*Rc1*Fz} \tag{6}$$

$$= 2.84pF$$

7) Calculation of feedback capacitor C_{C2}

$$C_{C2} = \frac{1}{2*\pi*Rc1*Fp} \tag{7}$$

$$= 2.1pF$$

III.OVER CURRENT PROTECTION (OCP)

A switching power supply is designed to operate safely at a predetermined output power level. Output beyond nominal current should be avoided, but in case an overcurrent or short-circuit condition occurs, the power supply must have some means of protection circuit. Hence over current protection is designed to protect converter against such abnormal current operation as it decreases efficiency by increasing the losses.

A. Design of OCP

The full load current is 12A.Hence the OCP circuit is designed to trigger for 125% of load current.

I_{in}= 15A (125% of load current)

V_{ref} = 2.5V, f_{sw} = 140 kHz, f_c= 1.4 kHz

$$C_1 = \frac{1}{2\pi f_c R_3} \tag{8}$$

$$= 31.5nF$$

R_{11} & R_{12}=15KΩ

R_8 =10KΩ limits the current to diode D1

nt limiting resistor to op-amp U1 &U2

$$(I_{in} * R_8) *(1+\frac{R_{12}}{R_{11}}) = 2.5V \tag{9}$$

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IV. UNDER VOLTAGE PROTECTION (UVP)

The under voltage protection circuits help in protecting the converter against under voltage operation. When the converter operates below the designed voltage levels, the input current drawn will be higher and this will lead to further rise in losses and thereby temperature of the components. This operation decreases the efficiency of the converter. Hence it's necessary to design a under voltage protection circuit such that it should trigger when voltage falls below 80%-90% of the rated voltage.

A. Design of UVP

The design starts with the under voltage consideration as follows

UVP = 80%-90% of input voltage

= 22V

B. Calculation of C1

$$Fcut\text{-}off = \frac{Fsw}{(6-10)} \tag{10}$$

= 14KHz

$$C1 = \frac{1}{2\pi * R7 * fcut\,off} \tag{11}$$

Let R7 = 105KΩ

C1 = 108.24nF.

R5 and R6 Calculation

$$Vref = \frac{Vin * R5}{R5 + R6} \tag{12}$$

Let Vref = 5.1V and R5 = 105KΩ

$$5.1 = \frac{22 * 105}{105 + R6}$$

R6 = 60KΩ

V. OVER VOLTAGE PROTECTION (OVP)

These are the circuits designed to clamp the output voltages to a safe value, when the output voltage tries to rise above some pre-determined value, thereby assuring the safety against over voltage conditions. To design OVP circuits an over voltage limit has been considered i.e 110% to 130% of actual output voltage.

A. Design of OVP

R4 and R5 Calculation

$$Vref = \frac{Vout * R4}{R5 + R4} \tag{13}$$

Let Vref = 2.5V and R4 = 20KΩ

$$2.5 = \frac{5.5 * 20}{R5 + 20} \tag{14}$$

R5 = 10.8KΩ.

$$Fcut\text{-}off = \frac{Fsw}{(6-10)} \tag{15}$$

= 14KHz

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Calculation of C1

$$C1 = \frac{1}{2\pi * R2 * fcut\ off} \quad (16)$$

Let R2 = 1KΩ

C1 = 11.36nF.

VI. SIMULATION CIRCUITS AND RESULTS

The designed values have been used in simulating the each circuit. The losses of the switches are neglected and appropriate components selected from the LTspice software which can withstand the internal stresses. The Fig 1 shows the simulated circuit of forward converter with type-2 compensation. The voltage feed-forward method helps in achieving good and fast dynamic response. The output voltage and current waveforms is shown in Fig 2 and 3 respectively.

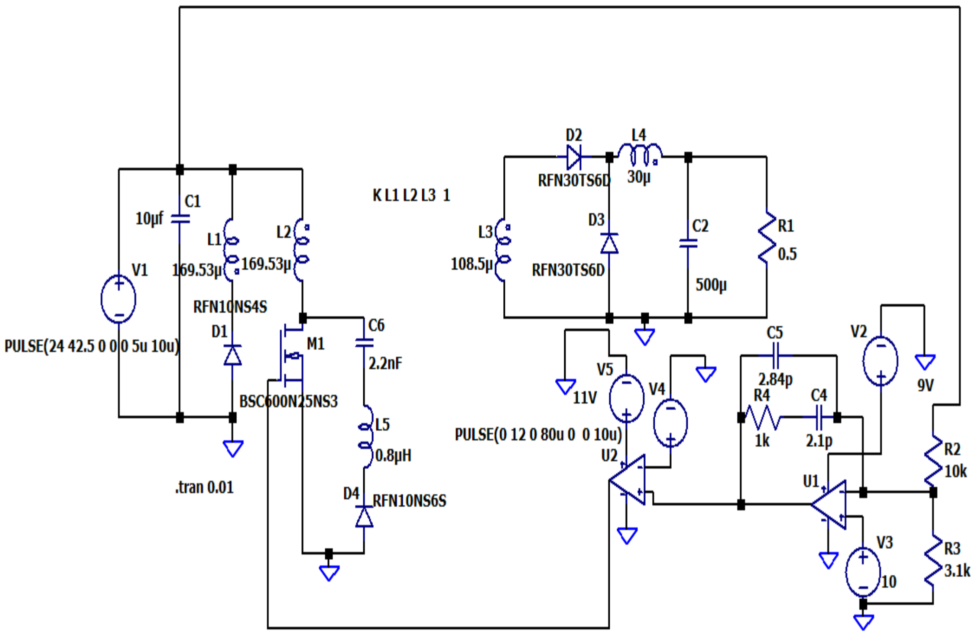

Fig 1 Simulation Circuit of Closed Loop Forward Converter

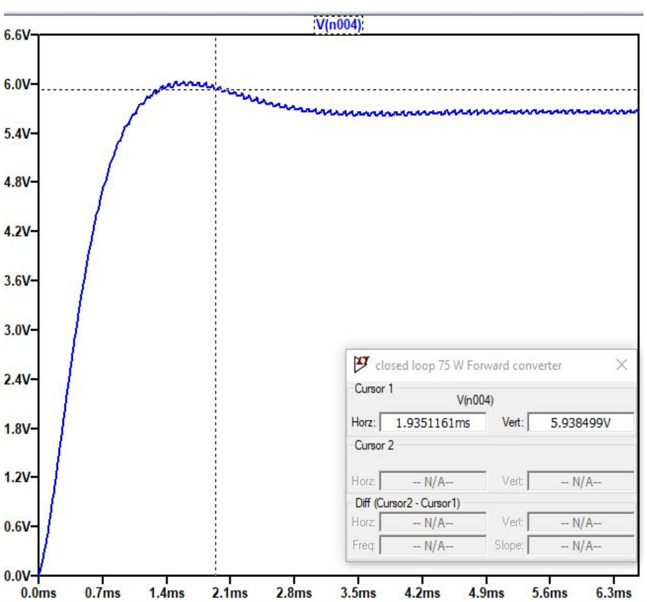

Fig 2 Output Voltage

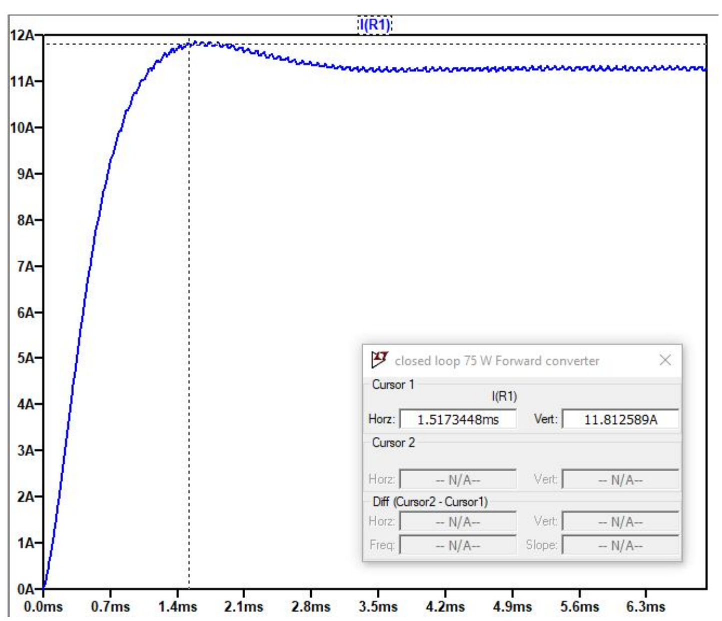

Fig 3 Output Current

The Fig 4 shows the forward converter with over current protection circuit. When the load current exceeds the designed value, the voltage across R13 is set to high and shutdown pin is triggered and hence, the converter is protected by overcurrrent with the use of OCP circuit.

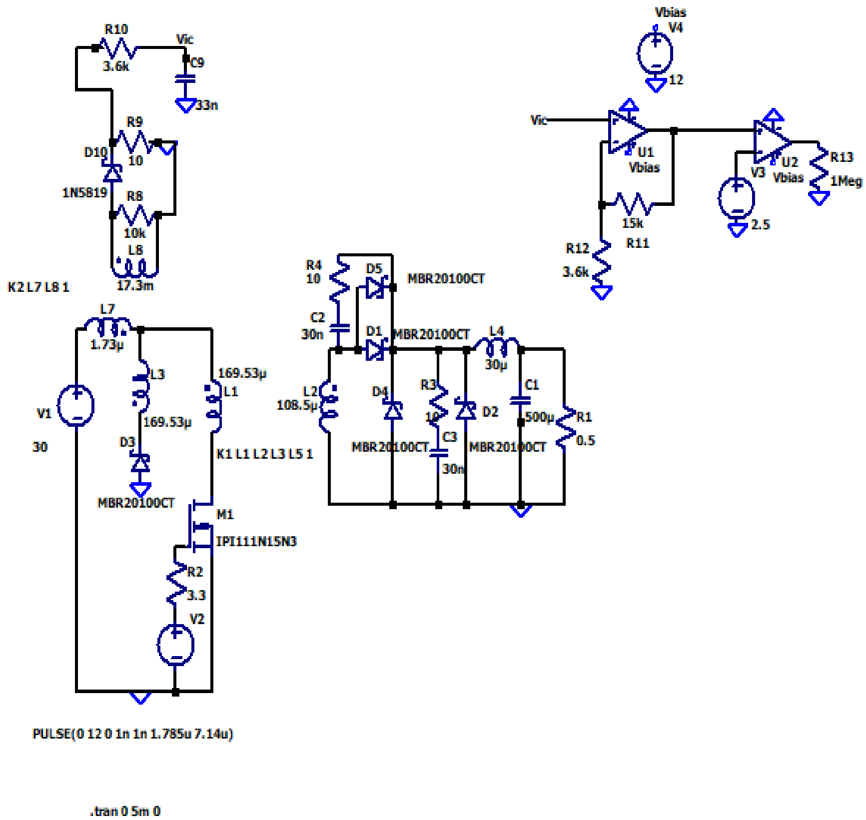

Fig 4 Forward Converter with OCP

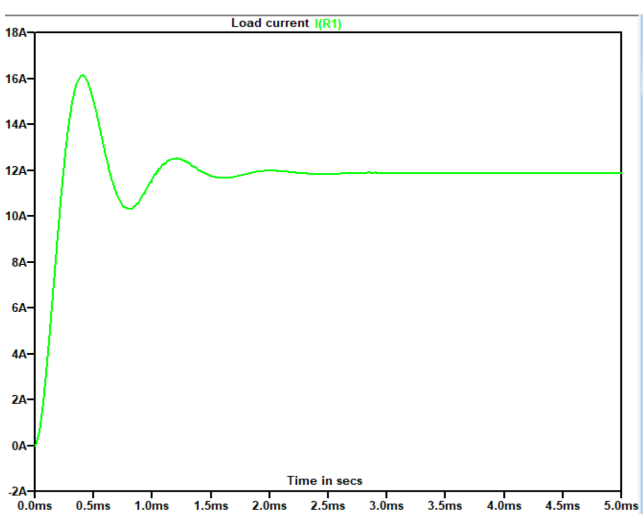

Fig 5 Under Normal Condition Load Current =12A

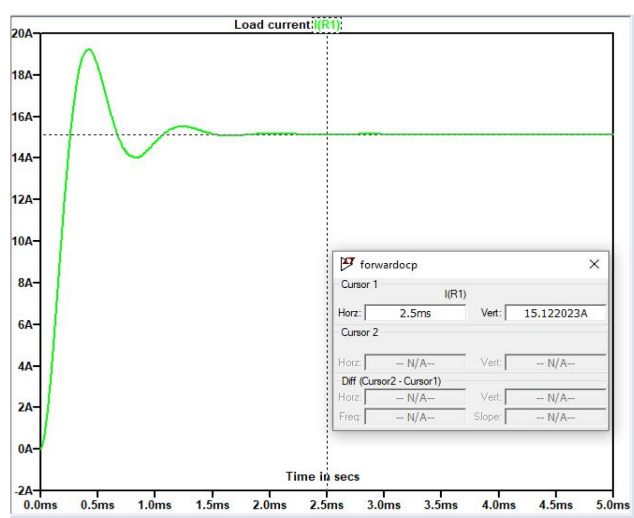

Fig 6 Under Abnormal Condition Load Current =15.12A

Fig 7 shows when the supply voltage is rated input and Fig 8 shows voltage across R8, which represents the shutdown pin voltage and it's low since input is rated.

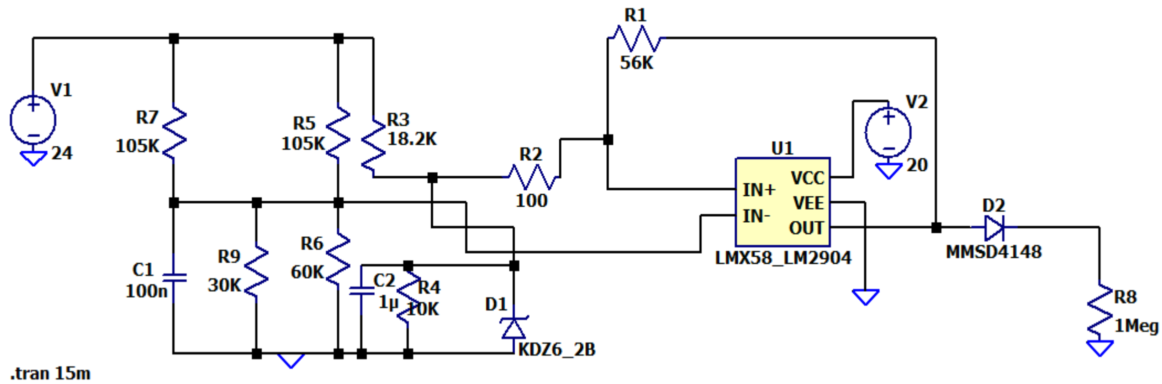

Fig 7 Simulation Circuit of UVP

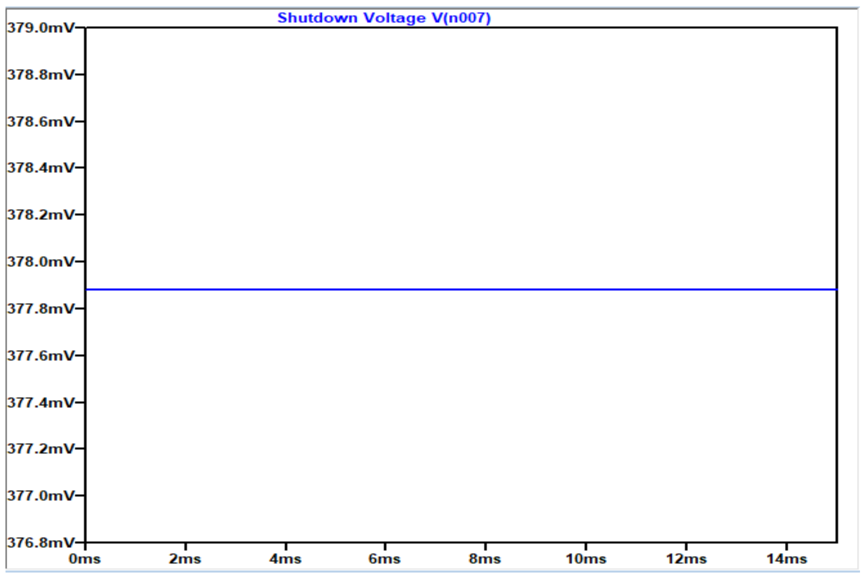

Fig 8 Under Rated Input Voltage

Fig 9 shows the when input voltage is 90% of minimum input voltage and Fig 10 shows the voltage across shutdown pin. The voltage is set to high interprets the converter is shutdown since it’s drawing more current.

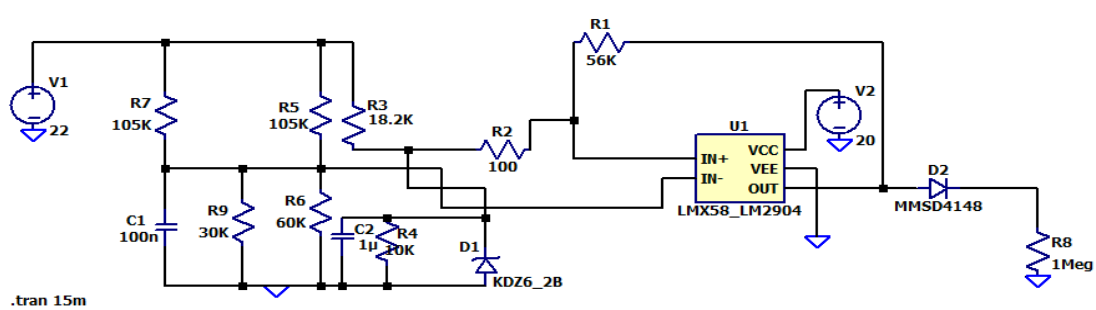

Fig 9 Simulation Circuit of UVP When Input is 22V

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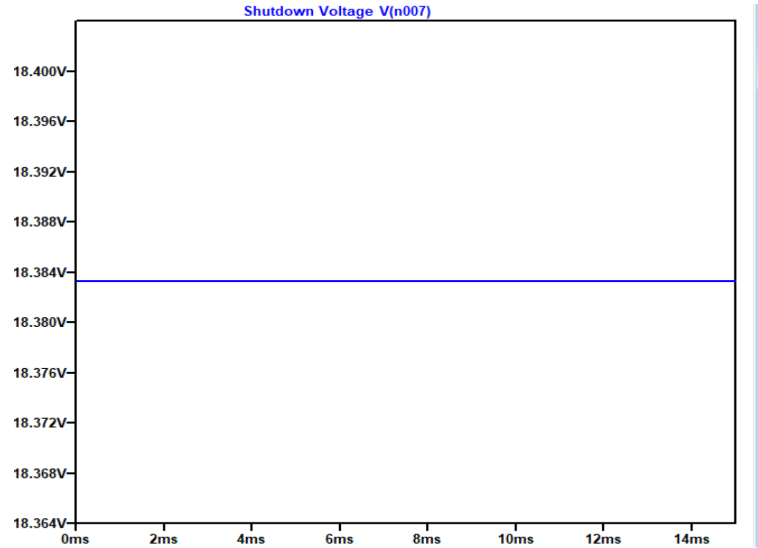

Fig 10 Under Voltage Condition (22V Input)

The simulated over voltage protection circuit is shown in Fig 11. The OVP is designed for 110%-130% of rated output voltage. When output exceeds this designed value, the shutdown pin is set to high and converter is shutdown.

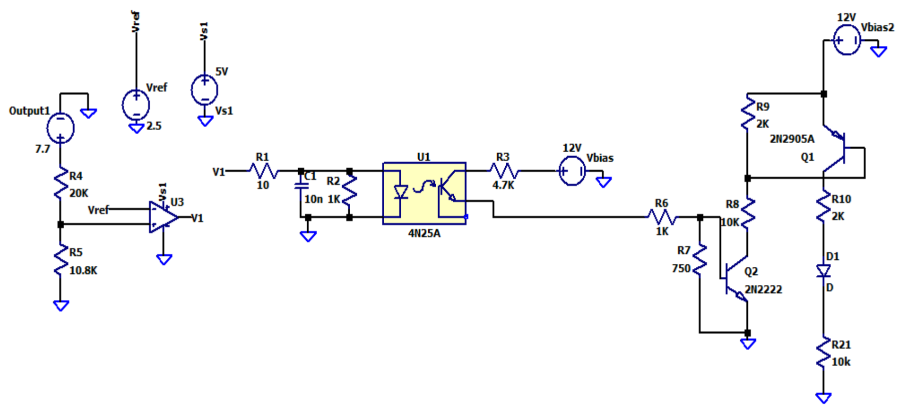

Fig 11 Simulation Circuit of Over Voltage Protection Circuit

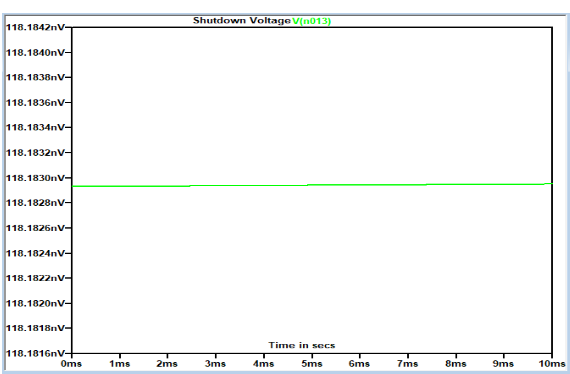

Fig 12 Actual Output Condition

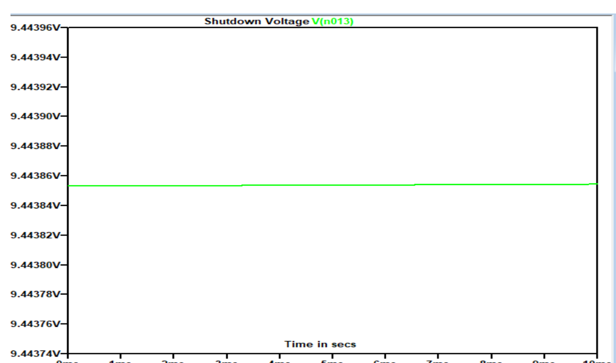

Fig 13 Over Voltage Condition

VII. CONCLUSION

The voltage feed-forward method helps in achieving fast dynamic response of output voltage against input voltage variations. Apart from this, protection circuits also play vital role in the safe operation of the converter as it protects from over voltage or current damage. Hence it's necessary to deign protection circuit for better reliability and effective working of the converter.

VIII. ACKNOWLEDGMENT

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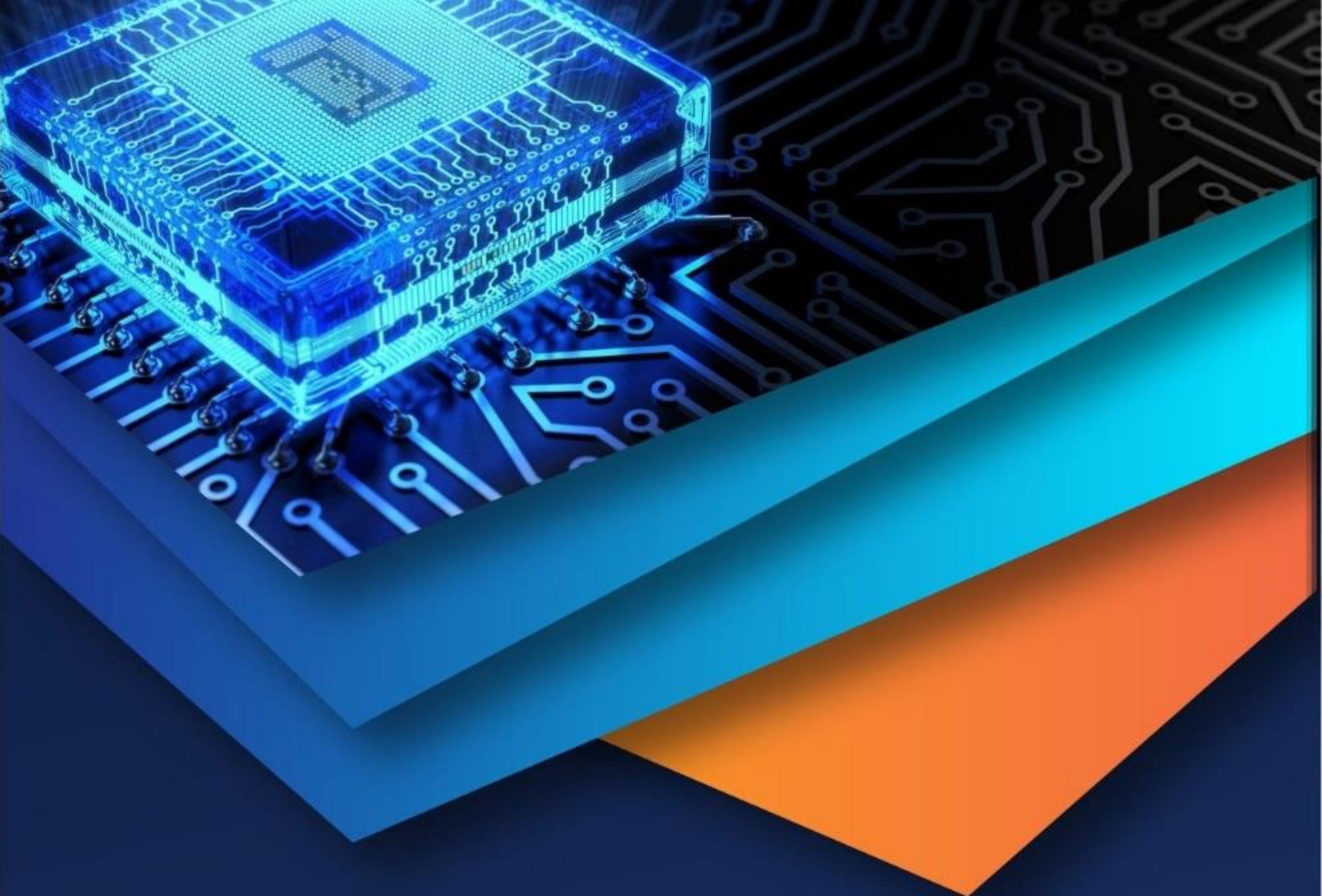

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