ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 5, May 2015

Performance Analysis for DC-DC Buck Converter with Fuzzy and Robust Controller

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ABSTRACT: The switch mode power supply (SMPS) has been achieved the high power density and high performance by developing the power semiconductor devices such as IGBT, BJT, MOSFET, and GTO etc. SMPS has the capacity to handle the variable loads and variable input voltage. The efficiency, weight and size of power supplies are a great area of concern for the power supply designers. This article introduces the method of intelligent regulation to control the Buck converter using the pulse width modulation switching by a fuzzy logic and robust controller. In this paper we use the buck circuit having power MOSFET as a switch and fuzzy logic and robust controller based PWM gate signals to the switch for controlling purpose. This paper describes the design of a fuzzy logic controller using output voltage of the converter as feedback for significantly improving the dynamic performance of buck dc-dc converter by using MATLAB/ SIMULINK. In the case of robust controller, the Buck converter output voltage remains constant irrespective of load and input voltage variations from 140V to 340V.

KEYWORDS: Fuzzy logic controller, Robust controller, DC-DC buck converter, MATLAB Simulink.

I.INTRODUCTION

The switched mode dc-dc converters are some of the simplest power electronic circuits which convert one level of electrical voltage into another level by switching action. Buck converter is widely used throughout the industry to convert a higher input voltage into a lower output voltage. This is due to their wide applications like power supplies for personal computers, office equipment, appliance control, telecommunication equipment, DC motor drives, automotive, aircraft, etc. The commonly used control methods for dc-dc converters are pulse width modulated (PWM) voltage mode control, PWM current mode control with proportional (P), proportional integral (PI), and proportional integral derivative (PID) controller. The advantages of these nonlinear controllers are their ability to react suddenly to a transient condition. The different types of nonlinear controllers are fuzzy logic controller, robust controller, hysteresis controller, sliding mode controller, boundary controller etc.

Robust control and fuzzy control techniques were used to regulate the output voltage considering the disturbances and uncertainties (input voltage and load variations) on the system. Each one of these controllers has good performance in certain operational conditions. Using robust control technique, the control signal makes the converter output response to have zero steady-state error. Robust control systems often incorporate advanced topologies which include multiple feedback loops and feed forward paths. The control lows may be represented by high order transfer functions required to simultaneously accomplish desired disturbance rejection performance with robust closed loop operation. On the other hand, using fuzzy control technique, the control signal makes the converter output voltage to have a fast transient response almost without overshoot. However, its output response has an undesirable steady-state error.

II. LITARATURE REVIEW

The research problem addressed in this dissertation is the design and implementation of controllers for buck converters using Fuzzy control methods. Digital control for DC-DC converters is theoretically interesting because it is a multi-disciplinary research. Theory in the areas of power electronics, systems and control, and computer systems are all needed to conduct research in digital control of DC-DC converters. The increasing interest in digital control of switch mode power supplies is shown in international conference proceedings and journal publications in the past few years.

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ISSN (Online): 2278 – 8875

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The dc-dc switching converters are the widely used circuits in electronics systems. They are usually used to obtain a stabilized output voltage from a given input DC voltage which is lower (buck) from that input voltage, or higher (boost) or generic (buck–boost) [1]. Most used technique to control switching power supplies is Pulse-width Modulation (PWM). The conventional PWM controlled power electronics circuits are modelled based on averaging technique and the system being controlled operates optimally only for a specific condition [2]-[3]. The linear controllers like P, PI, and PID do not offer a good large-signal transient (i.e. large-signal operating conditions) [3]-[4].

Buck converter when operated in CCM, gives a continuous output current, with smaller current ripple and low switching noise. CCM operation is usually preferred for large current applications, because it can deliver more current than the converter operating in DCM. However, a DCM converter has a much faster transient response and a loop gain that is easier to compensate than a CCM converter.

In June 2004, Perry and Sen proposed a design procedure that integrated linear control techniques with fuzzy logic. The small signal model for the converters and linear design techniques were used in the initial stages of fuzzy controller design. Simulation and experimental results were presented and compared with results of a digital PI controller. In July 2011, Feshki Farahani proposed a design of a fuzzy controller and comparing with PI digital controller. These comparisons show that the fuzzy controller has faster dynamic when compared with the PI digital classic.

III. BASIC PRINCIPLES OF BUCK CONVERTER

The buck is a popular non-isolated power stage topology, sometimes called a step down power stage. Power supply designers choose the buck power stage because the required output is always less than the input voltage. The basic buck dc-dc converter topology consists of a controlled switch S_w, an uncontrolled switch (diode) D, an inductor L, a capacitor C, and a load resistance R. The input current for a buck power stage is discontinuous, or pulsating. The output current for a buck power stage is continuous or non-pulsating because the output current is supplied by the output inductor/capacitor combination.

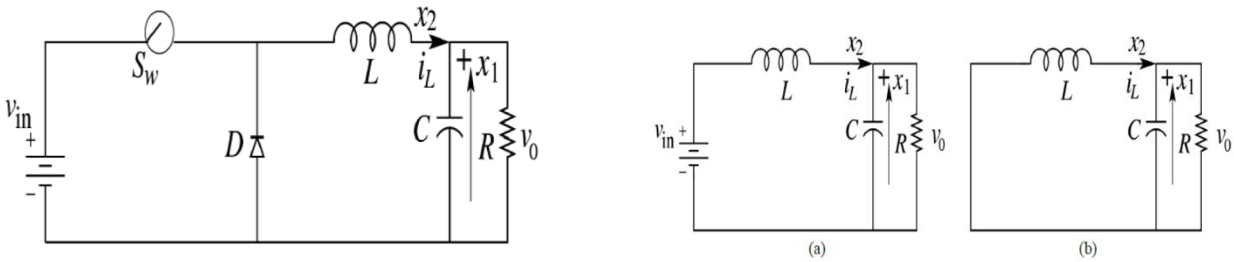

Figure 1: Buck Converter Circuit When Switch: (a) Turns On (b) Turns Off

In the description of converter operation, it is assumed that all the components are ideal and also the converter operates in CCM. In CCM operation, the inductor current flows continuously over one switching period. The switch is either on or off according to the switching function and this results in two circuit states. The first sub-circuit state is when the switch is turned on, diode is reverse biased and inductor current flows through the switch, which can be shown in figure 1(a). The second sub-circuit state is when the switch is turned off and current freewheels through the diode, which is shown figure 1(b).

Continuous Conduction Mode: When the inductor current flow is continuous of charge and discharge during a switching period, it is called Continuous Conduction Mode (CCM) of operation shown in figure 2(a). The converter operating in CCM delivers larger current than in DCM. In CCM, each switching cycle T_S consists of two parts that is D_1T_S and D_2T_S (D_1+D_2= 1). During, D_1TSinductor current increases linearly and then inD_2T_S it ramps down that is decreases linearly.

Discontinuous Conduction Mode: When the inductor current has an interval of time staying at zero with no charge and discharge then it is said to be working in Discontinuous Conduction Mode (DCM) operation and the waveform of inductor current is illustrated in figure 2(c). At lighter load currents, converter operates in DCM. The

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ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

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Vol. 4, Issue 5, May 2015

regulated output voltage in DCM does not have a linear relationship with the input voltage as in CCM. In DCM, each switching cycle is divided into of three parts that is D_1T_S, D_2T_S and D_3T_S ($D_1 + D_2 + D_3 = 1$). During the third mode i.e. in D_3T_S, inductor current stays at zero.

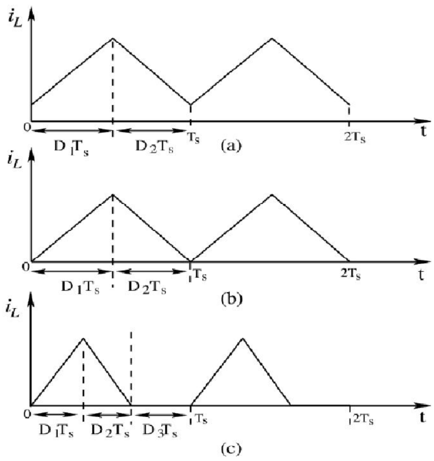

Figure 2: Inductor Current Waveform (a) CCM (b) Boundary Of CCM And DCM (c) DCM

Voltage-Mode Controlled Buck Converter: The voltage feedback arrangement is known as voltage-mode control when applied to dc-dc converters. Voltage-mode control (VMC) is widely used because it is easy to design and implement, and has good community to disturbances at the references input. VMC only contains single feedback loop from the output voltage.

The voltage mode controlled buck converter circuit is shown in figure 3. It consists of a controlled switch S_W (MOSFET), an uncontrolled switch diode D (diode), an inductor L, a capacitor C, and a load resistance R. The circuit shown in figure 3 is a non-smooth dynamical system described by two sets of differential equations:

$$\frac{di_L}{dt} = \begin{cases} \frac{v_{in} - v_0}{L}, & S_{w\ is\ conducting} \\ \frac{-v_0}{L}, & S_{w\ is\ blocking} \end{cases} \quad \ldots\ldots 1$$

$$\frac{dv_0}{dt} = \frac{i_L - \frac{v_0}{R}}{C} \quad \ldots\ldots 2$$

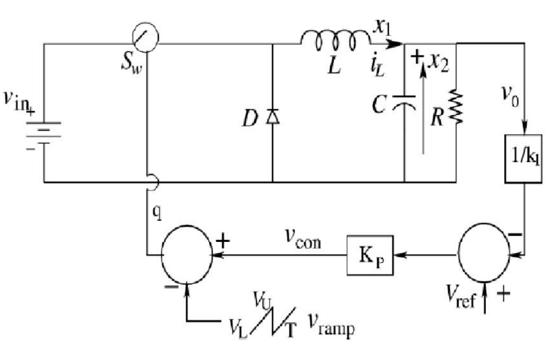

Figure 3: Block Diagram Of Voltage Mode Controller

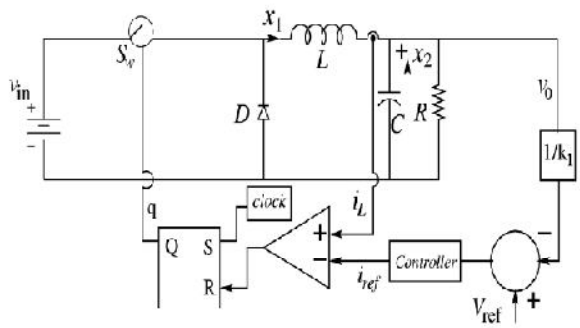

Figure 4: Block Diagram Of Current Mode Controller

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Current-Mode Controlled Buck Converter: Current-mode controlled dc-dc converters usually have two feedback loops: a current feedback loop and a voltage feedback loop. The inductor current is used as a feedback state. At the beginning of a switching cycle, the clock signal sets the flip-flop (q=1), turning on the (MOSFET) switch. The switch current, which is equal to the inductor current i_L during this interval, increases linearly. The inductor current i_L is compared with the control signal i_{ref} from the controller. When, i_L is slightly greater than i_{ref}, the output of the comparator goes high and resets the flip-flop (q=0), thereby turning off the switch. The switch will be turned on again by the next clock signal and the same process repeated.
Depending on the state of the switch, there are two circuit configurations are in the following differential equations:

$$\frac{di_L}{dt} = \begin{cases} \frac{v_{in} - v_0}{L}, & S_{w\ is\ conducting} \\ \frac{-v_0}{L}, & S_{w\ is\ blocking} \end{cases} \quad \dots\dots 3$$

$$\frac{dv_0}{dt} = \frac{i_L - \frac{v_0}{R}}{C} \dots\dots 4$$

If the switch position is expressed with the switching function, then q:

$$q = \begin{cases} 1 & S_w\ is\ closed \\ 0 & S_w\ is\ open \end{cases} \dots\dots 5$$

The control input signal is proportional to reference current i_{ref}. The reference current i_{ref} is a function of output of the controller to regulate the output voltage.

IV. DESIGN OF FUZZY LOGIC CONTROLLER

Fuzzy Logic Membership Function

The buck dc-dc converter is a nonlinear function of the duty cycle because of the small signal model and its control method was applied to the control of buck converters. In Fuzzy controllers mathematical model is not require. Instead, they are designed based on general knowledge of the plant (converter). The Fuzzy controllers are designed to adopt the varying operating points. Fuzzy Logic Controller is designed to control the output of buck dc-dc converter. In the fuzzy logic system two input variables, error (E) and change of error (E*) and one output variable is duty cycle of PWM output are used.

For each input and output variable fuzzy sets must be defined. As shown in Fig. 5. The three fuzzy subsets N (Negative), Z (Zero), P (Positive) have been chosen for input variables error (E) and change of error (E*). The Triangular shape has been adopted for the membership functions; the value of each input and output variable is normalized in the range [0 400] by using suitable scale factors.

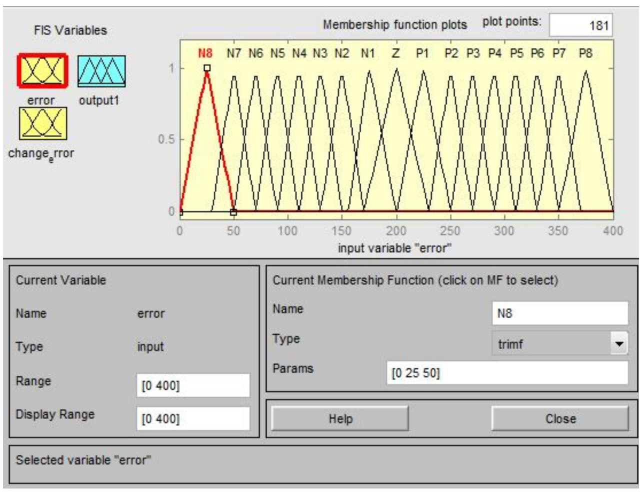

Figure 5: The Membership Function plots of error

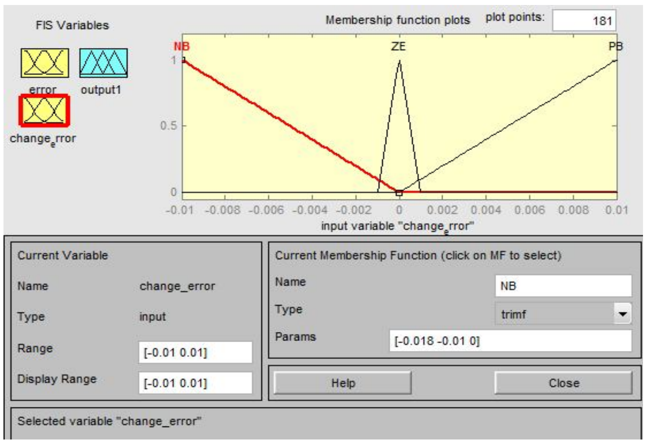

Figure 6: The Membership Function plots of change error

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

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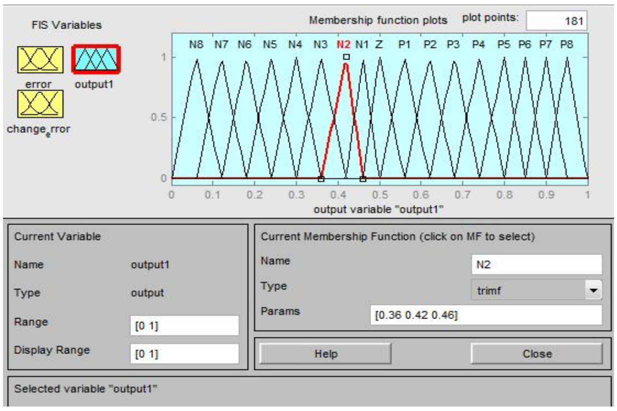

Figure 7: The Membership Function plots of duty ratio

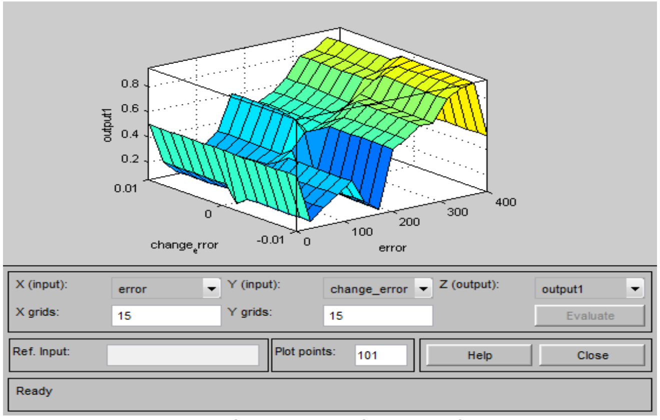

Figure 8: Surface View of Rules of FLC

Fuzzy Logic Table Rules

Fuzzy controller rules which are playing a very important role for controller simulation are obtained from the analysis of the system behavior. In their formulation it must be considered that, by using this controller we improve the converter performances in terms of dynamic response and robustness. 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 1:

TABLE-I RULE TABLE FOR FLC

E\E*	N	Z	P
N8	N7	N8	N6
N7	N6	N7	N8
N6	N5	N6	N7
N5	N4	N5	N6
N4	N3	N4	N5
N3	N2	N3	N4
N2	N8	N2	N3
N1	N8	Z	P2
Z	P1	Z	N1
P1	P2	P1	Z
P2	P3	P2	P1
P3	P4	P3	P1
P4	P3	P4	P3
P5	P6	P5	P5
P6	P7	P6	P5
P7	P8	P7	P6
P8	P8	P8	P7

Robust Controller : The robust controller is an H_∞ LMI (Linear Matrix Inequality) based state feedback controller that consists in a matrix K with gains K_1, K_2 and K_3 that multiplies the feedback states matrix x(t) – inductor current, output voltage and an integral action at the output voltage – generating the control signal u(t) (duty-cycle) to regulate the DC component of the output voltage. Figure 9 shows the robust controller block diagram implemented in Simulink. The

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techniques for minimizing the H_∞ norm must find a state feedback matrix K for a set of values entered into a polytope where its vertices are formed by the uncertainty matrixes. The matrix K must satisfy the control law:

$$u(t) = Kx'(t) \ldots \ldots \ldots . .6$$

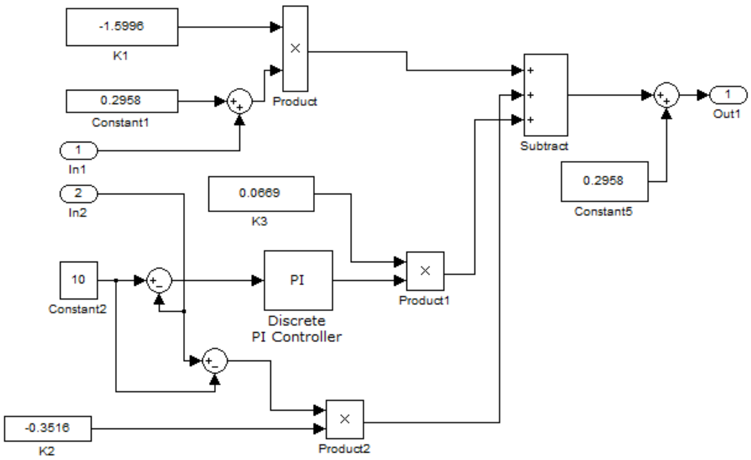

Figure 9: Block diagram for robust controller

V. SIMULATION RESULT AND DISCUSSION

Modelling in MATLAB/Sumulink For Fuzzy control Buck Converter:- This system carries out almost all the computations to produce the Output Voltage and Load Current Waveforms. The inputs to the subsystem are the Input Voltage, Duty cycle and Load Current. In addition, the following values need to be declared as masked parameters: Inductance (L), Inductance Series Resistance (RL), Capacitance (C), and Resistance (R).

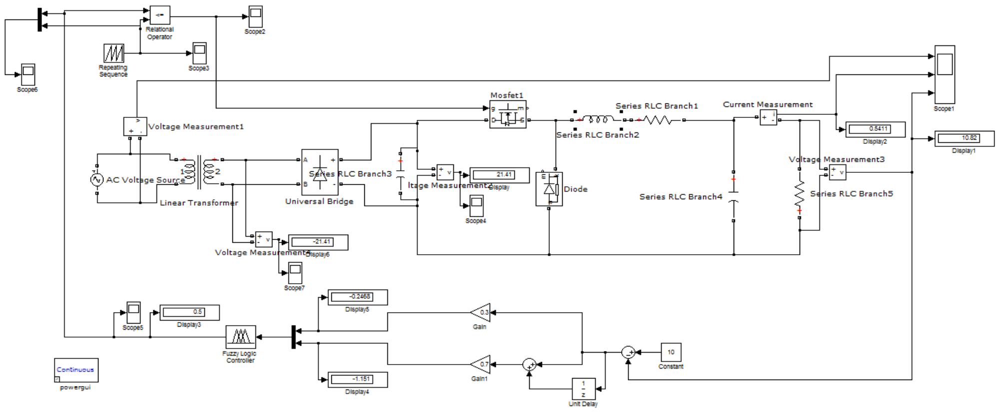

Fig. 10: Simulink Model of FLC based Buck Converter

Result:--

Input voltage:-- Here input voltage is 230 volt A.C

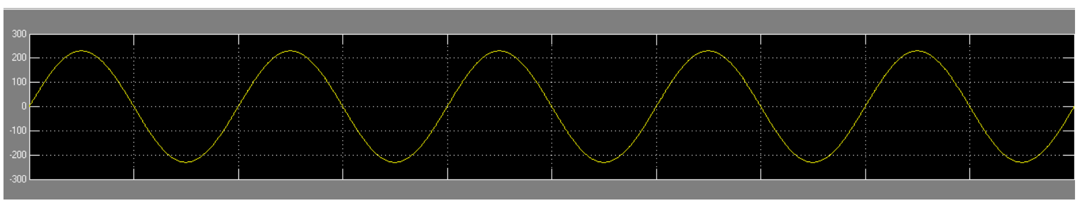

Figure 11: Waveform of Input voltage

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ISSN (Online): 2278 – 8875

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Output voltage and current:--

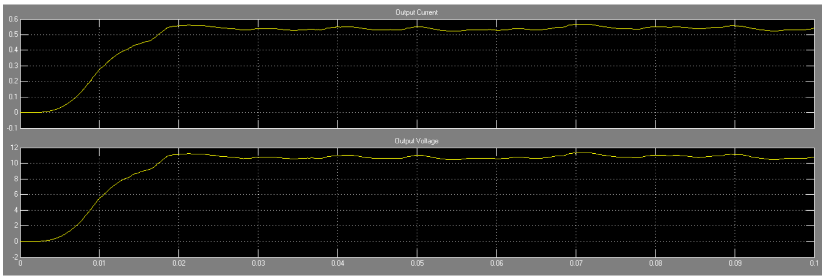

Figure 12: Waveform of output current and voltage

In this model, where dc-dc buck converter output voltage is controlled by the fuzzy logic controller. FLC generate a signal and it cut though the repeating sequence. Then generate a pulse which gives to mosfet. Here 230 volt ac supply pusses through a transformer and a bridge rectifier and produce dc voltage, then it step down to 10 volt. Output current is 0.5 amp.

Modelling in MATLAB/Simulink For Robust control Buck Converter:

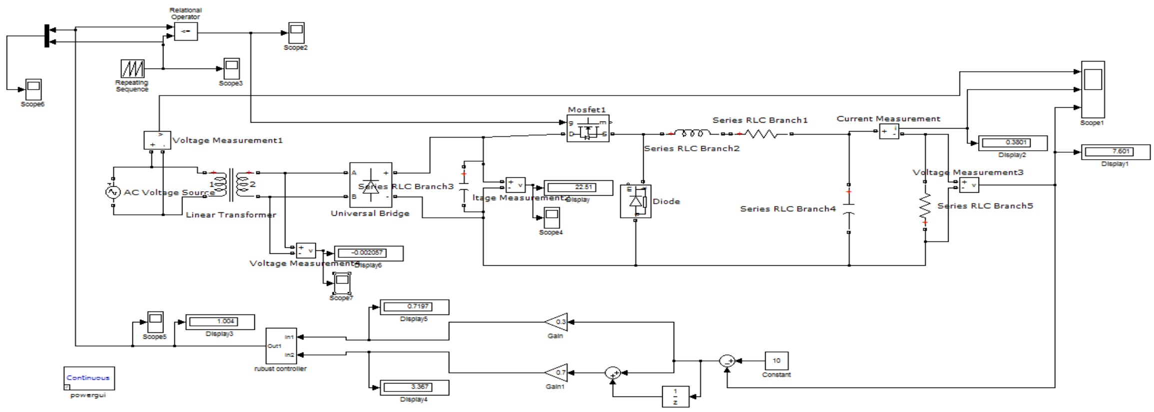

Figure13: Simulink model for robust control buck converter

Output Result :--

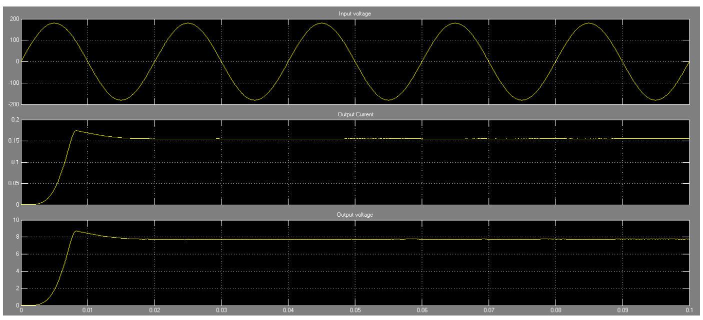

Figure 14: Output Voltage and current with 180 V input voltage at load resistance 50Ω

ISSN (Print) : 2320 – 3765
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(An ISO 3297: 2007 Certified Organization)

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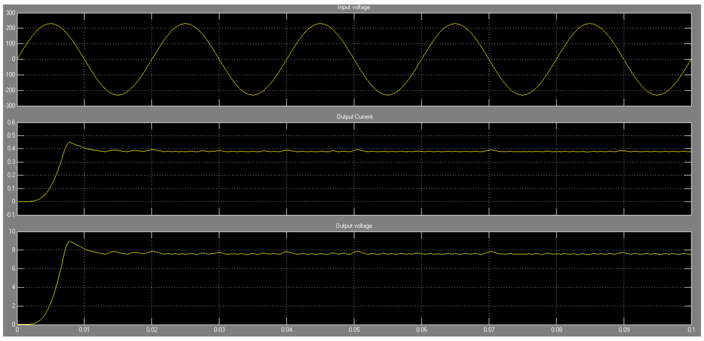

Figure 15: Output Voltage and current with 230 V input volt at load resistance 20Ω

SMPS operating in a Buck converter is a step down DC-DC converter controlled by robust controller used in many electronics devices. The same has been simulated by Using the MATLAB, an output voltage of 8V was obtained with an input range of 140V-340V. It does not depend on input voltage and load resistance; which is shown in the graph.

VI.CONCLUSION

Design of the fuzzy logic controller on control buck dc-dc converter by using MATLAB simulink has been successfully achieved. An algorithm based on the prediction of fuzzy logic controller, using the fuzzy rules parameter, is showing to be more convenient than the other circuit. SMPS operating in a Buck converter is a step down DC-DC converter used in many electronics devices. The same has been simulated by Using the MATLAB, an output voltage of 10V was obtained with an input range of 140V-340V DC supply. The waveforms across various points were obtained, studied and compared with the theoretical waveforms. The waveforms were found to be same to the desired waveforms. Hence, the circuit of buck dc-dc converter controlled by fuzzy logic controller confirmed the requirement of the proposed approach.

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ISSN (Print) : 2320 – 3765
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(An ISO 3297: 2007 Certified Organization)

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