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Analysis of DC-DC buck converter and their controller technologies.

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Abstract - Dc-dc power converters are employed in a variety of applications, including power supplies for personal computers, office equipment, spacecraft power systems, laptop computers, and telecommunications equipment, as well as dc motor drives. The DC-DC converter is used to provide variable DC output voltage from fixed DC input voltage. The buck converter is mostly use to decrease the output voltage. The paper presents the design & operation of Buck converter topology. Their calculations for finding specification of inductor coil and capacitor in order to obtain desired output have also been discussed in brief. The MATLAB simulation of specific designed model have been constructed and studied for various control methods like PID and fuzzy logic controller.

Keywords –PID, Fuzzy logic controller, DC-DC power.

I. INTRODUCTION

Almost all Electronic circuits are assumed to operate some supply voltage which is usually assumed to be constant in nature. A voltage regulator is a power electronic circuit that maintains a constant output voltage irrespective of change in load current. Many different types of voltage regulators with a variety of control schemes are used. With the increase in circuit complexity and improved technology a more severe requirement for accurate and fast regulation is desired. This has led to need for newer and more reliable design of dc-dc converters.. All regulators have a power transfer stage and a control circuitry to sense the output voltage and adjust the power transfer stage to maintain the constant output voltage. Since a feedback loop is necessary to maintain regulation, some type of compensation is required to maintain loop stability. Compensation techniques vary for different control schemes and a small signal analysis of system is necessary to design a stable compensation circuit. State space analysis is typically used to develop a small signal model of a converter and then depending on the type of control scheme used, the small signal model of converter is modified to facilitate the design of the compensation network. In contrast to a state space approach, PWM switch modeling develops a small signal of switching components of converter.[1]

DC –DC converters are power electronic circuits that convert a dc voltage to a different voltage level. There are different types of conversion method such as electronic, linear, switched mode, magnetic, capacitive. The circuits described in this paper are classified as switched mode DC-DC converters. These switch mode DC-DC converters are broadly classified in isolated and non-isolated topologies. Most of the times isolation served with the help of isolation transformers. These transformers fulfils two major objectives, first one is providing isolation and second one is voltage scaling with the help of turns ratio along with that multi-output can also be provided. The classification of SMPS are as follows [2]

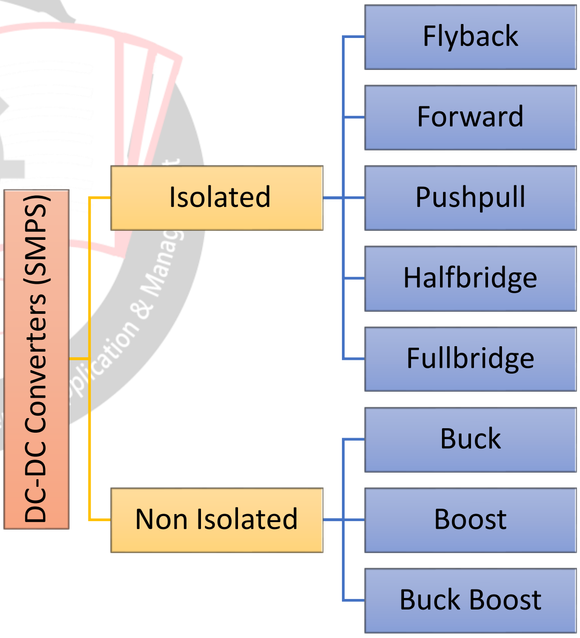

Figure 1: Classification of DC-DC Converters

The basic difference between isolated and non-isolated technologies is the presence of isolation transformer. Most of the application like including power supplies for personal computers, office equipment, spacecraft power systems, laptop computers, and telecommunications equipment, as well as dc motor drives.use non isolated topologies. These topologies provide variable DC output voltage for required application. In buck converter the output voltage can be decreased while to increase the output voltage boost converters are used. Whereas buck-boost converter provides wide range of output voltage by

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providing flexibility of increment and decrement of output voltage.[3]

II. Buck Converters Operation

The buck converter is also called as step down DC-DC converter as it can decrease the output voltage from provided input so mostly designers prefer this converter whenever they required lesser voltage than provided voltage. The input current for a buck power stage is discontinuous. , or pulsating, because the power semiconductor switch (SW). 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, that provides smooth DC waveform.

Figure 2 shows a simplified schematic of the buck power stage. Inductor L and capacitor C make up the effective output filter. The capacitor equivalent series resistance (ESR), RC, and the inductor dc resistance, RL, are included in the analysis. Resistor R represents the load seen by the power supply output. The diode D1 is usually called the catch diode, or freewheeling diode which provides path for inductive current.[4]

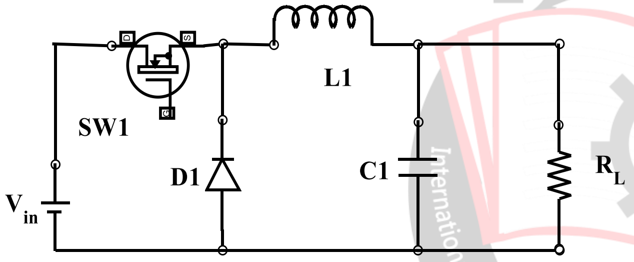

Figure 2:Buck Converter Circuit

A operation of buck converter is either in continuous or discontinuous inductor current mode. In continuous inductor current mode, current continuously flows in the inductor for entire switching cycle. While in discontinuous current mode, inductor current is falls to zero value for a particular portion of the switching cycle. It starts at zero, reaches peak value, and return to zero during each switching cycle. It is desirable for a power stage to stay in only one mode over its expected operating conditions as the frequency response changes significantly between the two modes of operation.[3]

There are two modes of operation of buck converter one is when SW is ON and second when SW is OFF. When SW is on ON inductor L1 delivers the current to the load, with a voltage (Vin - Vo) across L1, current rises linearly. The rise (in amps per second) is determined by,

$\Delta I / \Delta T = (Vin - Vo) / L1$

While when SW is OFF inductor L1 provides current to the load, As L1's magnetic field collapses, and current falls linearly through L1. The fall in current is entirely depends on voltage across inductor and value of inductance.

III. Design of Buck Converter

1. Duty Ratio Selection : In order to find the switch current the first step is to determine the duty cycle, D, for the maximum input voltage. The maximum input voltage is used because this leads to the maximum switch current.

   $(Max\ Duty\ Cycle)\quad D = \frac{Vin}{Vout \times \eta}$ Where η is Efficiency of converter.

2. Inductor Selection : The higher the inductor value, the higher is the maximum output current because of the reduced ripple current. In general, the lower the inductor value, the smaller is the solution size. The inductor must always have a higher current rating than the maximum current.

$$L = \frac{V_{out} \times (V_{in} - V_{out})}{\Delta I_L f_s V_{in}}$$

Where ,

ΔI_L is estimated ripple current of inductor which should be between 20% to 40% of maximum output current.

f_s is switching frequency.

3. Capacitor Selection : The best practice is to use low-ESR capacitors to minimize the ripple on the output voltage. Ceramic capacitors are a good choice if the dielectric material is X5R or better.

$$C = \frac{\Delta I_L}{8 f_s \Delta V_{out}}$$

Where ΔV_{out} is output voltage ripples.[5]

IV. Simulation of Buck converter

I. Open Loop System : First the buck converter has been simulated without supplying feedback from output. In the system Inductor, capacitor and other parameters are calculated according to above section of design of buck converter. Power Semiconductor switch which has been used in this system is MOSFET as it provide higher switching frequency. Simulated parameters are as follows.

Table 1: Simulation Parameters

Sr no	Parameter	Value
1	Vin	48V
2	Vout	5V-48V
3	D (Duty Ratio)	0.1-0.9
4	Fs (switching Frequency)	10KHz
4	L (Inductor)	15mH
5	C (Capacitor)	200µF

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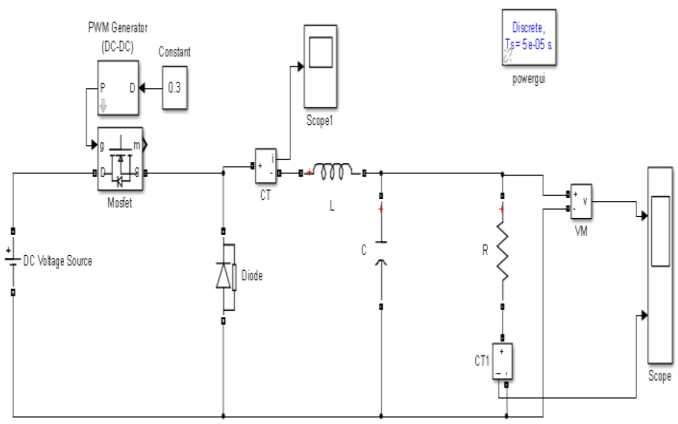

Figure 3: Simulation of Buck Converter Open-loop

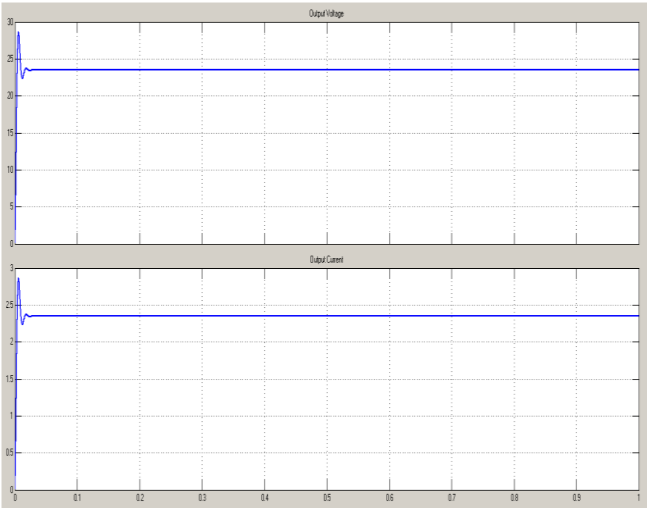

Figure 4 : Output Voltage & Current

Figure 3 shows the MATLAB simulation model of open loop buck converter for given parameters in table 1. In order to achieve 24V output voltage from 48V input voltage the duty ration need to set according to it. The output voltage and current waveforms of simulation has been shown in Figure 4 which shows a initial overshoot. The working of given model is in continuous current mode.

II. Close Loop Buck converter Using PID controller: A PID controller is feedback loop controlling mechanism. A PID controller corrects the error between a measured process value and a desired set point by calculating and then a corrective action adjust the process as per the requirement.[8]

The PID controller calculation involves three separate parameters, The Proportional value(P) determines the reaction to the current error, the Integral(I) determines the reaction based on the sum of recent errors and the Derivative (D) determines the reaction to the rate at which the error has been changing. The weighted sum of these three actions is used to adjust the process via a control element. By "tuning" the three constants in the PID controller the PID can provide control action designed for specific requirements. DC converters are modeled using state space analysis which directly determines state variables like inductor current and capacitor voltage. Requirement is to obtain a constant output voltage for input disturbance and this can be achieved by directly tuning the I value.[7]

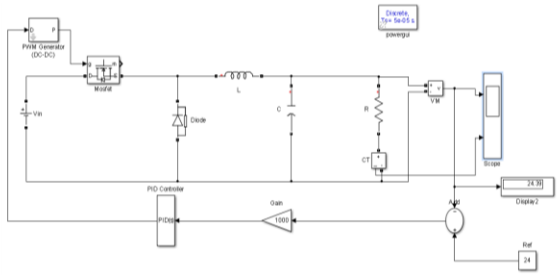

Figure 5: Close Loop Buck Converter PID

Figure 5 Shows the circuit of buck converter using PID controller. In this simulation model we can vary the output voltage by changing the required reference voltage. Reference voltage is compared with existing output voltage and then error between reference and output voltage is fed to PID controller. In this the Kp, Ki & Kd gains of PID are selected according to 'ZieglerNichols ' Method. John G. Ziegler and Nathaniel B. Nichols introduced ZieglerNichols method. In this method, the I and D gains are first set to zero. The "P" gain is increased until it reaches the "critical gain (Kc)" at which the output of the loop starts to oscillate. The Output of PID controller is given to PWM generator which generates pulses with corrected duty cycle so as to reduce error and stable output can be obtain even with the unstable input voltage. The controlled output voltage and current waveforms of Controlled Buck converter has been shown in Figure 6.

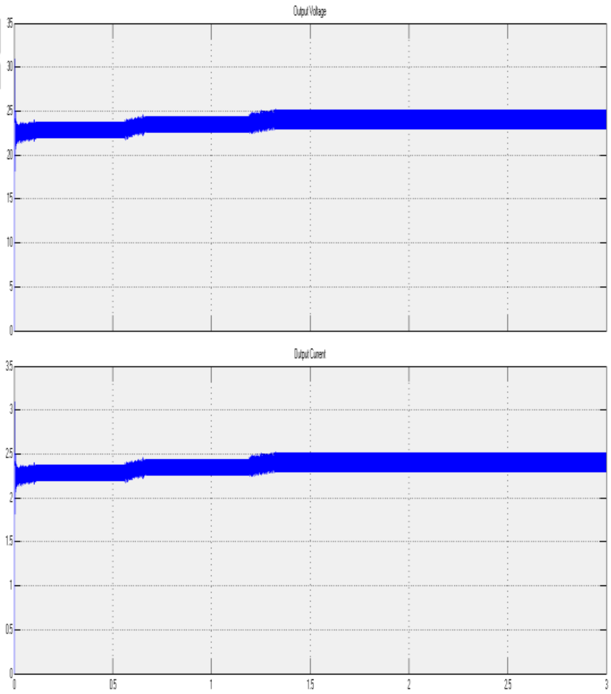

Figure 6: Output voltage of Buck Using PID

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III. Close Loop Control of Buck Converter using Fuzzy Logic Control : In fuzzy controller controlling is determined from a set of simple linguistic rules. The development of rules requires only understanding of the process to be controlled and does not require any mathematical model. Fuzzifier, knowledge base, inference engine, defuzzifier are the four important parts of the fuzzy logic system.

a. Fuzzification: In this block classification of input data is done into suitable linguistic values or sets.
b. Knowledge base: In this block fuzzy rules are written in the form of IF….THEN statements.
c. Inference engine: In this block decision making is done.
d. Defuzzification: In this block fuzzy control action is converted into crisp signal.

The derivation of the fuzzy control rules is based on human knowledge about what to do if system output get increase or decrease and based on the following criteria

- When the converter output is not reference value and it far from reference point, duty cycle should be large to bring the output to the reference point rapidly
- When the converter output is less than desired output voltage then duty cycle should be increased to get target output.
- When converter output is greater than desired output voltage then duty cycle should be decreased to get target output.

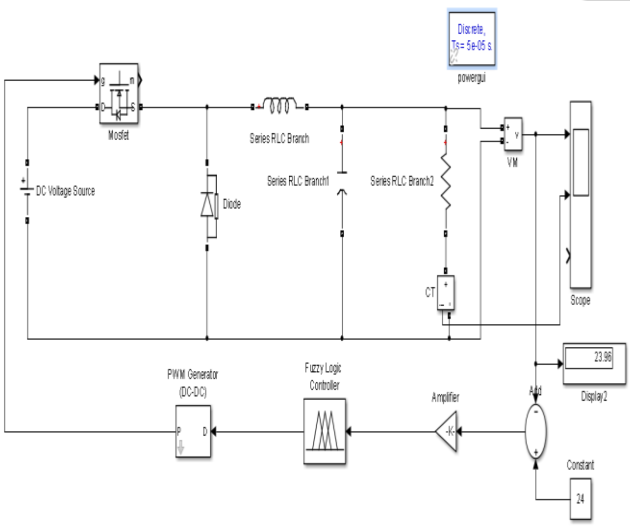

Figure 7: Buck Converter With Fuzzy Logic Controller

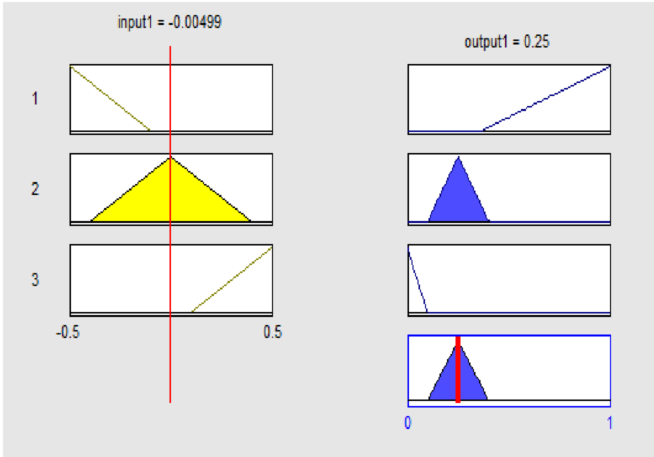

Figure 8: Rules for Fuzzy Logic

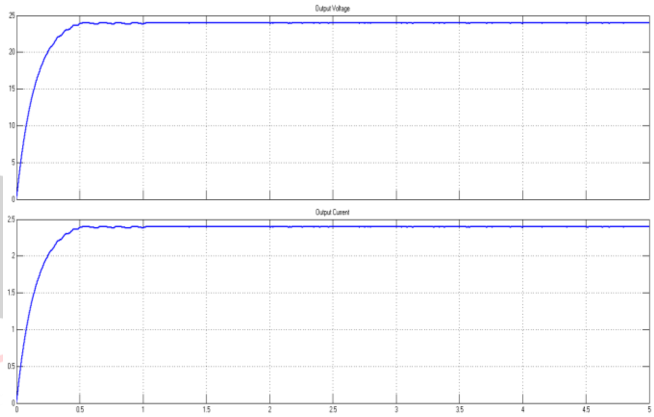

Figure 9 : Output Voltage & Current of Buck Converter Using Fuzzy Controller

V. CONCLUSION

In conclusion of this paper is the comparison between voltage output for DC-DC buck converter between open loop, PID controller and fuzzy logic controller through MATLAB Simulink package. Simulink's input voltage was set at 48V and the voltage reference was set at 24V. The analysis on the deviation of voltage resulted that the difference between reference voltage setting and the output voltage is always lower. Comparison between open loop, PID and FLC shows that, the open loop circuit has a bit higher on the deviation of voltage. The PID & FLC has a lesser deviation of voltage and proved that it is such a better performance on control the deviation of voltage during the boost mode.

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