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Modelling, Design and Control of a Step-Up Chopper Using PID Controller

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***Abstract*— This paper explains the modeling, designing and implementation of control logic using PID controller over step-up DC-DC converter. Mainly this paper proposed for buck converter should be operated at a particular switching frequency. It can be done by considering on time and off time of the switching period separately. This modeling of converter is useful while designing the digital feedback controller system. This design gives the reliable converter dynamic operation. In this paper a PID controller architecture is designed and this design is based on the loop shaping of the proposed frequency domain transfer function. By using this variable frequency method smooth output voltage regulation and dynamic performance is achieved.**

I. INTRODUCTION

Generally we consider two control objectives during controlling of DC-DC converters, they are namely performance and efficiency. The better efficiency can be achieved by the controlling scheme operated at constant on time and off time at different load conditions so that the switching power losses should be minimum. And better performance will be achieved by comparing the converters operated at different controlling laws. In simple words the DC-DC converters are inherently variable control structures. A sliding mode control (SMC) technique is the one of the analog controlling technique[3-4],[8]. This is based on the large signal representation of the circuit and it has a simple design procedure. Nowadays the digital controlling techniques will be more used in the implementation of the converter operation. So with the limited resolution and bandwidth technique of the digital control methods the analog control techniques are weakened. The time optimal control(TOC) technique is the one of the digital control method, in this a non linear interrupt based logic is added in parallel to the linear feedback loop to give optimal response[5-6].

II. BUCK CONVERTER MODEL

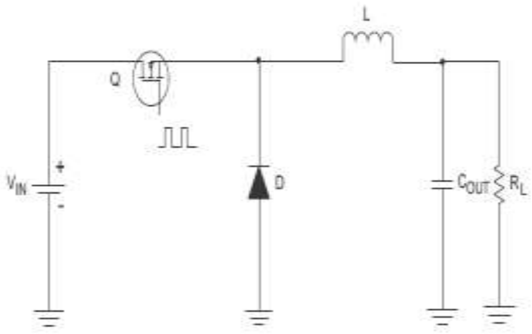

Fig.1:Classic buck converter

The fig.1 represents a dc-dc buck converter. In the buck converter the DC supply connected to the diode rectifier and it use as a controlled switch to ensure the unidirectional flow of power from input to output. One inductor and one capacitor is used to store and transfer the energy from supply to the load. The voltage and current waveforms can be smoothen by filter. The circuit is assumed to be operating in continuous condition mode (CCM). Here the capacitor used is large enough to offer a constant output voltage. [7]

In the description of converter operation, all the components like inductor, capacitor etc. are assumed to be ideal when the converter operates in CCM.

Here V_o = 14volts

V_{in} = 50 volts

$$D = D_{min} = \frac{14}{50} = 0.28$$

INDUCTOR PARAMETERS

$$L_{critical} = \frac{(1-D)}{2f}\frac{Vo}{I_{o\,ccm}} \qquad (1)$$

$$I_{lmax} = I_{omax} + \frac{(1-D)Vo}{2Lf} \qquad (2)$$

$$\Delta I_l = \frac{(1-D)Vo}{Lf} \qquad (3)$$

f=35$\times 10^3$Hz

MOSFET PARAMETERS

$\mathbf{V_{ds}}$=V_s=50v

$$I_d = D.I_{omax} \tag{4}$$

MOSFET LOW SIDE

$V_{ds} = V_s = 50V$

$$I_f = (1-D)I_{omax} \tag{5}$$

CAPACITOR PARAMETERS

$$V_{c_{max}} = Vo + \frac{\%v \times Vo}{2} \tag{6}$$

Where %v=0.01

$$C_o = \frac{(1-D)}{8Lf^2}\frac{1}{\%v} \tag{7}$$

$$I_{c_{rms}} = \frac{(1-D)Vo}{2\sqrt{3}Lf} \tag{8}$$

MINIMUM INPUT CAPACITANCE

$$C_{in} = \frac{(1-D)D \times I_{omax}}{f\Delta Vin} \tag{9}$$

Where $\Delta V_{in} = 5\%$ of V_{in}

LOSSES

- Static loss

$$P_{static} = \left[Io\sqrt{D} \times \sqrt{\left(1+\frac{\Delta I_l}{2I_0}\right)}\right]^2 R_{ds\ on} \tag{10}$$

Where $R_{ds\ on}$=8mΩ

- Switching losses

$$P_{(Ton)} = \frac{IoV_{in}Ton}{6T} \tag{11}$$

$$P_{(Toff)} = \frac{IoV_{in}Toff}{6T} \tag{12}$$

$$P_{(Tsw)} = P_{(Ton)} + P_{(Toff)} \tag{13}$$

DESIGN PARAMETERS

TABLE I

PARAMETERTS	**VALUES**
Input voltage(V_{in})	50V
Output voltage($V_{o)}$)	14V
Critical inductance ($L_{critical}$)	2.88×10^{-4}H
Maximum load current(I_{lmax})	20.5A
Supply frequency(f)	35KHz
Change in load current(ΔI_l)	1A
Duty ratio or minimum duty ratio(D or D_{min})	0.28
Drain current(I_d)	5.6A
Drain to source voltage (V_{ds})	50V
I_f	14.4A
$I_{o\ ccm}$	500mA
$V_{c\ max}$	14.07V
$C_{critical}$	2.55×10^{-5}F
inductance	330×10^{-6}H
capacitance	220×10^{-6}F
C_{in}	100×10^{-6}F
$I_{c\ rms}$	1.152×10^{-4}A
$C_{in\ min}$	4.608×10^{-5}F
ΔV_{in}	2.5V
P_{static}	0.9184W
$\%V_o$	0.01
$P_{T\ on}$	8.1×10^{-5}W
$P_{T\ off}$	2.91×10^{-4}W
P_{SW}	3.72×10^{-4}W
T_{on}	14nS
T_{off}	50nS

III. STATE MODEL

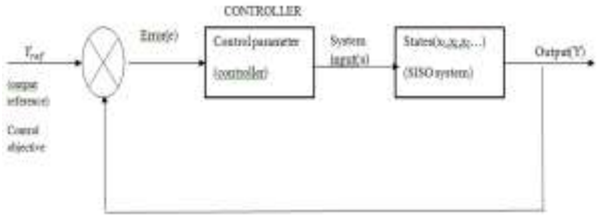

Fig.2: state model with controller

1. *Inductor current*

$$\frac{di_l}{dt} = \frac{1}{L}[(Vi - Vc)D + (-Vc)(1-D)]$$

$$\frac{di_l}{dt} = \frac{1}{L}Vi.D + \frac{1}{L}(-Vc)$$

$$\boldsymbol{\frac{di_l}{dt} = \frac{V_i.D}{L} - \frac{Vc}{L}} \tag{14}$$

2. *Capacitor voltage*

$$\frac{dVc}{dt} = \frac{1}{C}\left[\left[\left(i_l - \frac{V_c}{R}\right) - \left(i_l - \frac{V_c}{R}\right)(1-D)\right]\right.$$

$$\boldsymbol{\frac{dV_c}{dt} = \frac{1}{C}i_l - \frac{V_c}{RC}} \tag{15}$$

SIMPLIFICATION AND LINEARIZATION OF STATE MODEL

Fig.3:state model

New variables

$$i_l = x_1 \qquad D = u$$

$$V_c = x_2 \qquad y = V_c = x_2$$

The state equations can be re written as

$$\frac{dx_1}{dt} = \frac{V_i.u}{L} - \frac{x_2}{L} \qquad (16)$$

$$\frac{dV_c}{dt} = \frac{1}{C}x_1 - \frac{x_2}{RC} \qquad (17)$$

Here the system is already linear as it is satisfying the homogeneity and superposition property

TRANSFER FUNCTION MODELING

$$\frac{dx_1}{dt} = \frac{V_i.u}{L} - \frac{x_2}{L}$$

$$\frac{dx_2}{dt} = \frac{1}{C}x_1 - \frac{x_2}{RC}$$

Here

Output=y=x_2

Input=u

By taking the laplace transformation of the state equation

$$SX_1 = -\frac{1}{L}Y + \frac{V_i}{L}U$$

$$SY = \frac{1}{C}X_1 - \frac{X_2}{RC}$$

The final transfer function can be given by

$$\frac{Y(S)}{U(S)} = \frac{\frac{V_i}{LC}}{S^2 + \frac{1}{RC}S + \frac{1}{LC}} \qquad (18)$$

Equation (18) represent the transfer function of a Buck converter

IV. DESIGN OF FEEDBACK CONTROLLER

Here it can be noted that the input and the output power of the converter are not the same as the plant system input and output

By simplifying and linearizing the system[6]

Fig.4:linearized state model

The controller is the key component in achieving a well controlled and high performance system.

Here we are going to use the PID controller to be the standard control material. For the feedback control we are taking the difference between the control objective and the actual output to get the error signal.

The error signal is fed to the controller must determine the correct input to the system that will cause the output to reach the control objective.[5]

THE PID CONTROLLER

A proportional-integral-derivative (PID) is a control loop feedback mechanism commonly used in industrial control and automation. A PID controller is used to calculates the error value as the difference between the measured process variable and the desired set point or equilibrium point. The controller used to minimize the error by adjusting the process by the use of a manipulated variables.

The PID controller algorithm includes three separate constant parameters which are commonly known as error constant parameters, and accordingly it can be termed as three-term control: the proportional, the integral and the derivative parameters ,commonly denoted as P, I, and D symbols. By simply putting, these values can be interpreted in the function of time: P depends on the present error, I depends on the accumulation of past errors, and D is predicting the future errors values, based on current rate of change. The weighted sum of these three actions is used to adjust the process via a controlling element such as the position of a control valves, dampers, or the power supplied to the heating element. For a discrete time control system, the terms namely PSD, for proportional-summation-derivative, are used. [1-2]

A PID controller depends only on the measured process variable, not on knowledge of the underlying process, making it a broadly useful controller. By tuning the three parameters P,I & D in the controller algorithm, the controller can provide control action for a specific process requirements. The response of the controller can be explained in terms of the responsiveness of the controller to an error, the degree to which the controller overshoots the set point or equilibrium point, and the degree of system oscillation. Keeping in mind that the use of the PID algorithm for control does not guarantee optimal control of the system or system stability. Some of the applications may require using only one or two terms to provide the appropriate system control. This can be achieved by setting the other parameters to zero. A PID controller can be used as a PI, PD, P or I controller in the absence of the respective control actions. PI controllers are most common, as derivative action is sensitive to measurement noise, whereas the absence of an integral term may prevent the system from reaching its target value due to the control action.

MODELLING OF FEEDBACK CONTROL SYSTEM

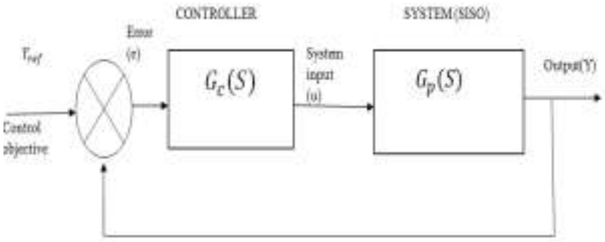

Fig.5; feedback controller model

TRANSFER FUNCTION OF A FEEDBACK CONTROL SYSTEM

$$\boldsymbol{G_c(S)} = \frac{k_d S^2 + k_p S + k_i}{S} \qquad (19)$$

$$k_d = derivative\ error\ constant$$

$$k_p = proportional\ error\ constant$$

$$k_i = integral\ error\ constant$$

The closed loop transfer function for a buck converter with controller feedback is given by

$$\frac{Y(S)}{Y_{ref}(S)} = \frac{\frac{V_i}{LC}k_d S^2 + \frac{V_i}{LC}k_p S + \frac{V_i}{LC}k_i}{S^3 + \left[\frac{1}{RC} + \frac{V_i}{LC}k_d\right]S^2 + \left[\frac{1}{LC} + \frac{V_i}{LC}k_p\right]S + \frac{V_i k_i}{LC}} \qquad (20)$$

V. SIMULATION RESULTS

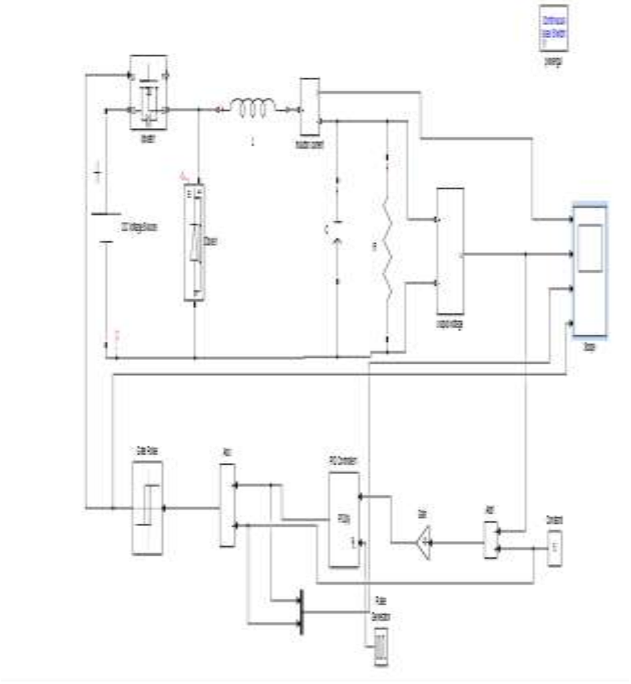

Fig.6: Simulation model

WITHOUT CONTROLLER

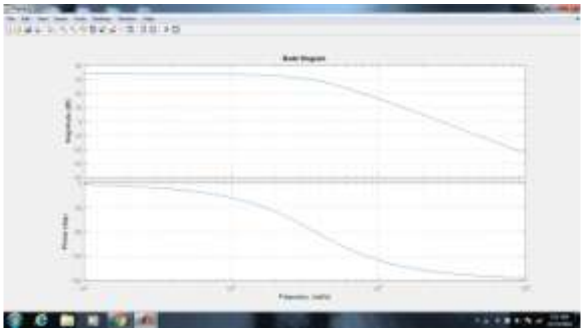

Fig.7: Loop shaping/bode diagram

Fig.8: loop shaping parameters

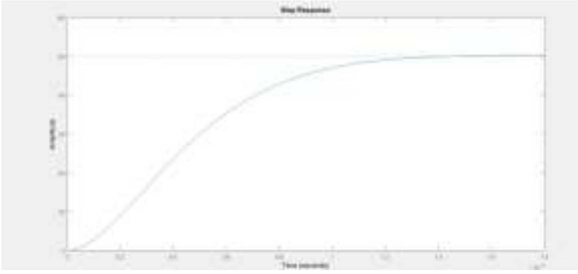

Fig.9: Step response without controller

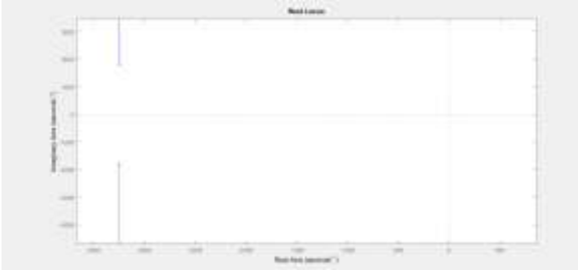

Fig.10: pole placement /root locus plot

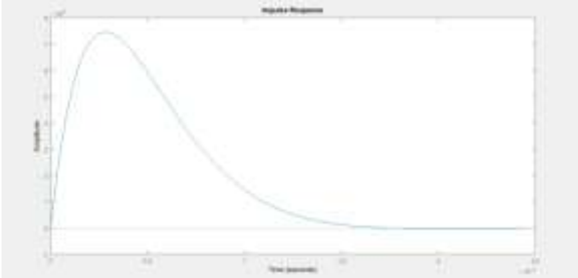

Fig.11: impulse response

WITH CONTROLLER

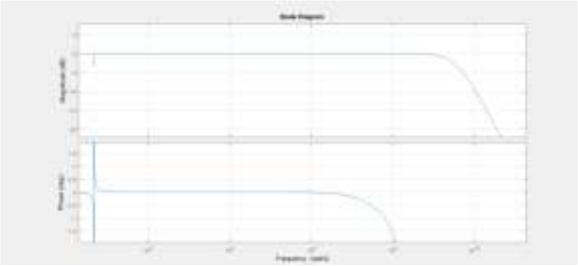

Fig.12: bode diagram/loop shaping with controller

Fig.13: loop shaping parameters

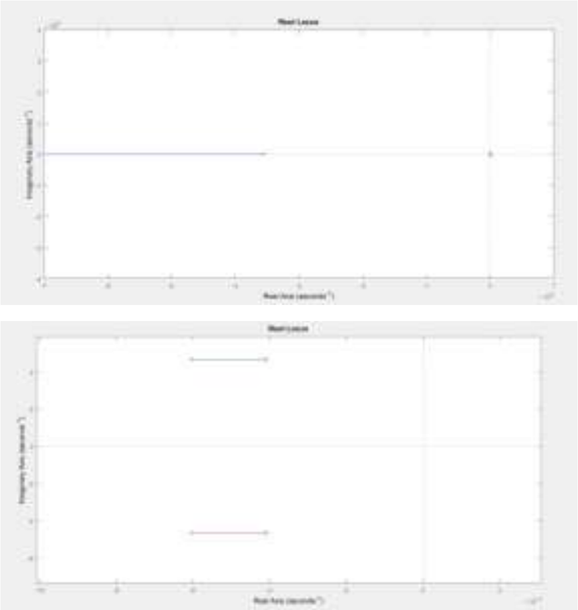

Fig.14: pole placement/root locus

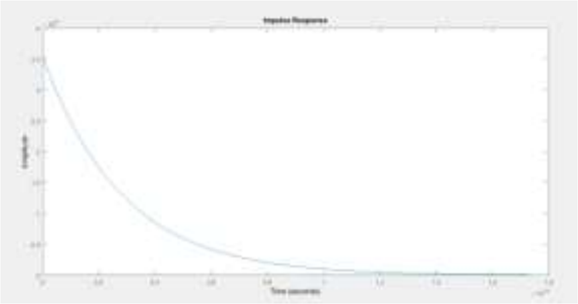

Fig.15: impulse response

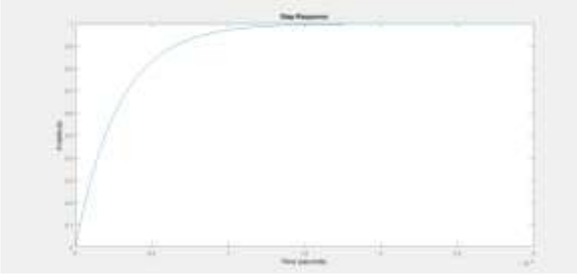

Fig.16: step response

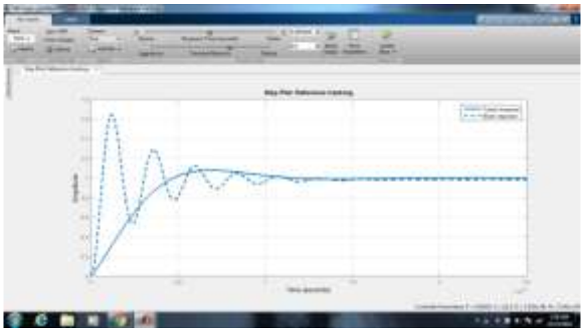

Fig.17;PID controller tuning

Fig.18: inductor ripple current

Fig.19: output of PID controller

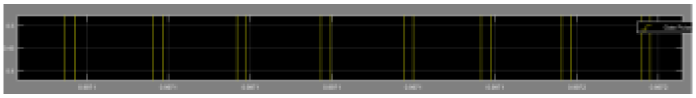

Fig.20: gate pulse (10V)

Fig.21: output ripple voltage (0.001v)

Fig.22: designed circuit with controller

VI. CONCLUSION

In this paper we analyzed the operation of classic Buck converter with and without controller .By the use of PID controller in it ,the transient impulse response characteristics is improved which is shown in the above simulation results. By tuning the PID controller the respective error constants i.e. proportional, integral and derivative error constants are optimized. The effect of this PID controller can be seen over the loop shaping and pole placement characteristics which is comparatively more stable as compared to the system without the controller. The future scope of the work is to implement the closed loop control of this converter for renewable energy source applications (mainly in inverters).

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