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Design and Development of an Adaptive control using Model following technique for DC-DC Boost converter

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***Abstract*—- This paper presents the analysis & control of output voltage and speed of response of a Boost converter. The converter has been operated in continuous conduction mode and analysis has been carried out by means of an averaged model. To attain the faster speed of response of the proposed boost converter the Model following adaptive controlling scheme is proposed to be a suitable adaptive control scheme. The simulation is performed using MATLAB/SIMULINK software and results are provided.**

I. INTRODUCTION

DC-DC converters find wide applications in regulated switch-mode dc power supplies and in dc motor drive applications. The switched mode power supplies are nonlinear time varying systems and hence the design of high performance control is usually a challenging issue for both the control engineering engineers and power electronics engineers. A great deal of effort has been directed in developing the modeling and control techniques of various DC–DC converters. Classic linear approach relies on the state averaging techniques to obtain the state-space averaged equations. In this paper a boost converter is designed and analyzed in continuous conduction mode of operation. Occurrence of non-linear phenomena like ripples and speed of response is analyzed by varying the load resistor and supply voltage [1], [2].After analyzing the results of both the Pole Placement control and MRAC [3] – [5] a new controlling method is adapted with the boost converter named as MODEL FOLLOWING. The nonlinear behaviour of the boost converter has been investigated with the help of this averaged model. Simulations are carried out using MATLAB / SIMULINK software and the results are presented.

A ANALYSIS AND DESIGN OF BOOST CONVERTER

A. Analysis of Boost Converter

The boost converter is capable of providing output voltage greater than the input voltage. It is also known as "ringing choke" (or) a step-up converter. In boost converter, inductor L acts as the primary means of storing and transferring energy from the source to the load. The circuit diagram of a boost-type dc-dc switching converter operating in the continuous conduction mode is shown in Figure.1.

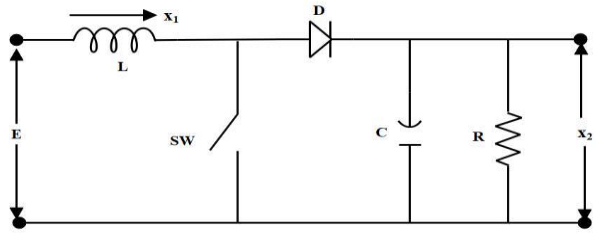

Figure 1. Circuit Diagram of Boost Converter

The average output voltage is $$x2 = \frac{E}{1-k} \quad (1)$$

The inductor current $x_1(t)$ and the capacitor voltage $x_2(t)$ are given by,

$$\dot{x}_1 = \frac{E}{L} \quad (2)$$

$$\dot{x}_2 = -\frac{1}{RC}x_2 \quad (3)$$

$$\dot{x}_1 = \frac{E}{L} - \frac{x2}{L} \quad (4)$$

$$\dot{x}_2 = \frac{x}{C} - \frac{x_2}{RC} \quad (5)$$

B. State Space Equations and Transfer Function

Due to the switching action the boost converter has non-linear behaviour, it becomes necessary to develop a non-linear model of the system. The method currently used in power electronic literature is the state-space averaging technique. The state space equations are,

$$\dot{x}_1 = \frac{k-1}{L}x_2 + \frac{E}{L} \qquad (6)$$

$$\dot{x}_2 = \frac{1-k}{C}x_1 + \frac{1}{RC}x_2 \qquad (7)$$

The Transfer function of boost converter can be achieved by solving the state space equations as,

$$\frac{y(s)}{E(s)} = \frac{1-k}{LCs\left(s+\frac{1}{RC}\right)+(1-k)^2} \qquad (8)$$

C. Design Consideration of Converter

The boost converter operating in continuous conduction mode is designed in this paper. The converter parameters are chosen as in Table I :

TABLE I. DESIGN PARAMETERS OF BOOST CONVERTER

Parameter	Values
Supply Voltage , E	5V
Output Voltage (x2), Vo	10V
Output Power, P	20 W
Duty ratio, D	0.5
Switching frequency, fs	10 KHz
Device Drop (VF)	0.7 V
Inductor, L	150 mH
Capacitor, C	220 µF

D. Analysis of Simulation Result

The boost converter operating in continuous conduction mode is modeled and simulated using MATLAB software. The simulated waveforms of output voltage $x_2(t)$ is shown in Figure. 2.

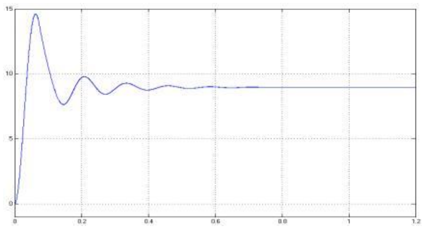

Figure2 .Output Voltage of Boost Converter

The actual output of the proposed boost converter is as shown in Figure. 3.

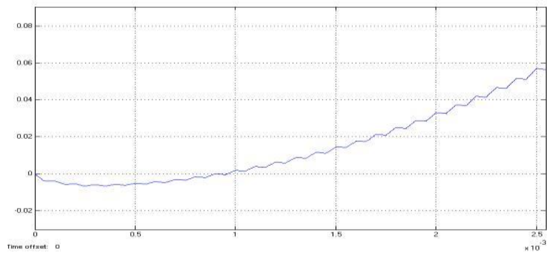

Figure 3. Transient response of the boost converter

The output voltage of the boost converter initialize becomes negative and after some becomes positive and reach a steady value. It is very clear from the graph that there is dip occurring when the output response of the boost converter starts. Due to undershoot there is a delay in reaching the steady state, undershoot limit increases, maximum limit on the achievable closed loop gain is imposed and limits the bandwidth since the closed loop gain increased to regulate the output voltage the control techniques fails to give desired response. To overcome these undesirable effects caused by undershoot a suitable control technique is required. Hence in the present work an adaptive control technique for the control need to be attempt has been made to apply.

III. MODEL FOLLOWING CONTROL

The Model following control method is the combination of both Pole placement and MRAC schemes. Controller part is taken from Pole placement scheme. Reference and Error Generating Principle is taken from MRAC scheme.

A. Pole Placement control

It is a simple method for control design. The idea is to determine a controller that gives desired closed-loop poles. In addition it is required that the system follows command signal in a specified manner. Let u_c be the control signal or set input, u be the actual input to the actual converter, y be the output of the converter and v be the disturbance then the general block diagram of the converter is given in figure. 4.

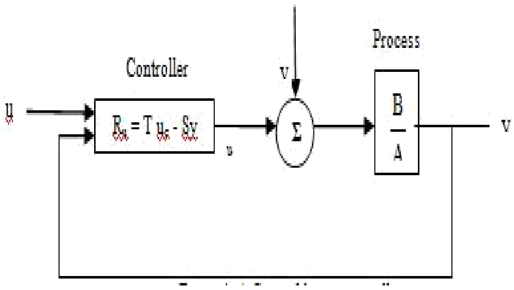

Figure 4. A General linear controlle

Thus, a process can be simply defined as

$$Ay(t)=Bu(t)$$

It can be written as,

$$y(t) = \frac{B}{A} u(t)$$

The control law for Pole Placement Control is,

$$R u = T u_c - S y$$

Where R,S,T are the Control Parameters.
From (10) and (11),

$$y(t) = \frac{BT}{AR + BS} u_c(t)$$

$$u(t) = \frac{AT}{AR + BS} u_c(t)$$

From the above input and output equations its clear that the denominator polynomial is same decides the nature of the equation. Let the closed loop characteristic equation be,

$$A_c = AR + BS$$

The output of a Transfer function depends upon the characteristic polynomial or the poles of that transfer function. And a model is taken whose output is satisfying all the requirements of converter. Let it's transfer function be, Bm / Am . If the proposed converter should give the output as the model converter then the poles of the proposed converter should be placed as in the place of model's poles. i.e.,

$$AR+BS = A_c$$

where, $A_c = BT$

The model's transfer function is assumed as,

$$\frac{B_m}{A_m} = \frac{\omega^2}{s^2 + 2\zeta\omega s + \omega^2}$$

$$r_1 = a_0 + 2\zeta\omega - (a_1 + a_2)$$

$$s_0 = \frac{\omega^2 + 2\zeta a_0 \omega - (a_1 a_2 + (a_1 + a_2) r_1)}{b}$$

$$s_1 = \frac{a_0 \omega^2 - a_1 a_2 r_1}{b}$$

$$T = \frac{\omega^2 (s + a_0)}{b}$$

where, $R = s + r_1$

$$S = s_0 S + s_1$$

a1 and a2 are the poles of the proposed converter. By substituting the values in the controller law the controller is designed.

B. Model Reference Adaptive Control (MRAC)

The model-reference adaptive system may be regarded as a servo system in which the desired performance is expressed in terms of a reference model, having desired response to a command signal. A block diagram of the system is shown in Figure. 5.

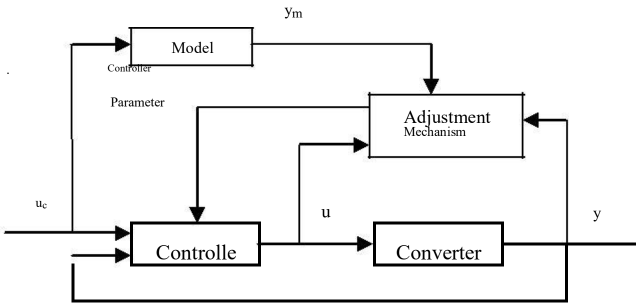

Figure 5. Block Diagram of MRAC

The model reference adaptive control method shown consists of four parts,

- A plant containing unknown parameters.
- A reference model for compactly specifying the desired output of the control system.
- A feedback control law containing adjustable parameters.
- An adaptation mechanism for updating the adjustable parameters.

The MIT rule is the original approach to model-reference adaptive control. To present the MIT rule, a closed-loop system in which the controller has one adjustable **parameters θ is considered. The desired closed**-loop response is specified by a model whose output is y_m. Let e be the error between the output y of the closed-loop system and the output ym of the model. One possibility is to adjust parameters in such way that the loss function is minimized.

$$J(\theta) = \frac{1}{2} e^2$$

To make J small, it is reasonable to change the parameters in the direction of the negative gradient of J, that is ,

$$\frac{d\theta}{dt} = -\gamma \frac{\partial J}{\partial \theta} = -\gamma e \frac{\partial e}{\partial \theta}$$

This is celebrated as MIT rule. The partial derivative **∂e / ∂θ, which is called the sensitivity derivative of the system**
tells how the error is influenced by the adjustable parameter. The control law is

$$u = \theta_1 u_c - \theta_2 y$$

Where θ_1 and θ_2 are controller parameters, u_c is control signal or set input and y is the output. The process can be

written as ,

$$\frac{dy}{dt} = -ay + bu$$

The model can be described as

$$\frac{dy_m}{dt} = -ay_m + bu$$

The controller has two parameters. If they are chosen to be,

$$\theta_1 = \theta_1^{\bullet} = \frac{b_m}{b}$$

$$\theta_2 = \theta_2^{\bullet} = \frac{a_m - a}{b}$$

The input-output relations of the system and the model are the same. This is called perfect model- following. To apply the MIT rule, introduce the error,

$$e = y - y_m$$

where y denotes the output of the closed-loop system. It follows from (28)

$$y = \frac{b\theta_1}{p + a + b\theta_2} u_c$$

where p = d/dt is the differential operator.

$$\frac{\partial e}{\partial \theta_1} = \frac{b}{p + a + b\theta_2} u_c$$

$$\frac{\partial e}{\partial \theta_2} = -\frac{b^2\theta_1}{(p + a + b\theta_2)^2} u_c = -\frac{b}{p + a + b\theta_2} y$$

These formulae cannot be used directly because the process parameters a and b are not known. Approximation are therefore required. One possible approximation is based on the observation that

$$p + a + b\theta_2 = p + a_m$$

From this,

$$\frac{\partial \theta_1}{\partial t} = -\gamma \left(\frac{a_m}{p + a_m} u_c \right) e$$

$$\frac{\partial \theta_2}{\partial t} = \gamma \left(\frac{a_m}{p + a_m} y \right) e$$

C. Model Following Control

Even though MRAC gives output precise, ripple free, output with no overshoot, it takes a very long time to reach steady state. A new adaptive method, namely model following which is a combination of pole placement and model reference is being adopted. The block diagram of Model Following is as similar as the MRAC but the control used in Model Following differs from MRAC as well as Pole placement.

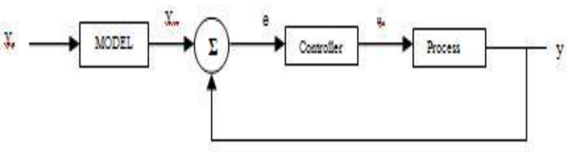

Figure 6. Block Diagram for Model Following Control

The control law used in this Model following is found from (15) and (16). To attain the output as same as the Model's output the final condition is,

$$T = S$$

After substituting this condition the control law as,

$$Ru = Tu_c - Sy + Te$$

As the control parameters cannot be changed widely, as the load changes widely in Pole placement. Similarly, the adaptation gain in MRAC cannot be changed and hence cannot reach steady state faster as the load changes. But from the control law (18) it is very clear that the input to the converter u adapts with the change in error, where the error change reflects the load variation. So finally the proposed control law gives the desired output.

IV. SIMULATION RESULTS

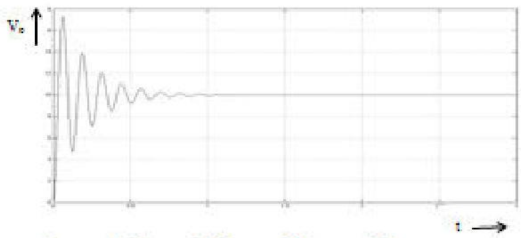

Figure 7. Output Voltage of Proposed Boost Converter

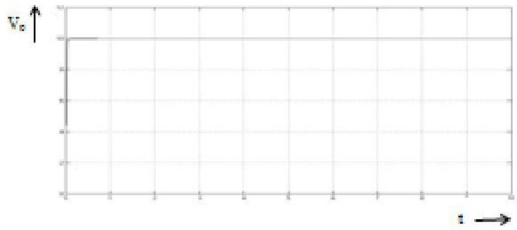

Figure 8. Output Voltage of Model Boost Converter

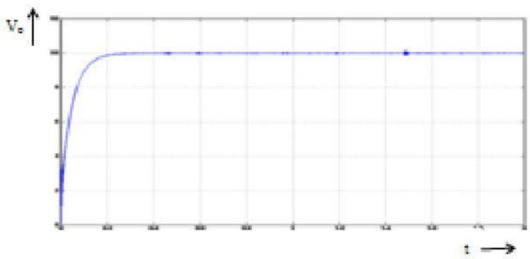

Figure 9. Output Voltage in Pole Placement Control

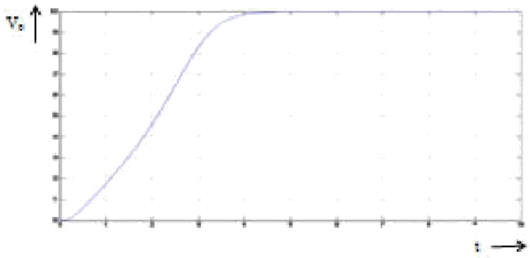

Figure 10. Output Voltage in MRAC

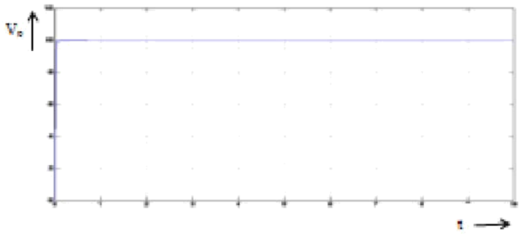

Figure 11. Output Voltage in Model Following control

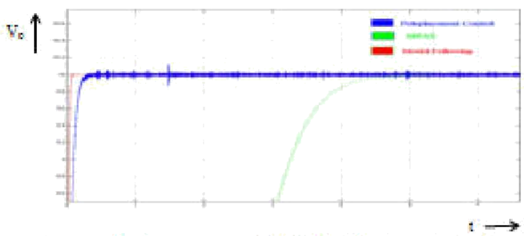

Figure 12. Comparison of Model following with other Controlling schemes

V. CONCLUSION

From the following table of comparison, it is evident that Model Following is the most suitable adaptive control scheme for the proposed boost converter.

TABLE II. PARAMETERS OF BOOST CONVERTER

Control	Settling Time (Seconds)	Ripples in Output
Pole placememt	0.34	YES
MRAC	6.4	NO
Model Following	0.18	NO

VI. FUTURE WORK

As the satisfactory results achieved for the proposed boost converter through MATLAB/SIMULINK model, in future this proposed boost converter and the Model following controlling scheme will be verified through hardware implementation so as to prove Model Following is the best adaptive controlling scheme rather than Pole placement control as well as Model Reference Adaptive Control scheme.

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