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Control of DC-DC boost converter using Fuzzy Logic and its stability analysis

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ABSTRACT
In this study, comparison between two controllers i.e. PID controller and fuzzy logic controller is done for the proposed dc-dc closed loop boost converter. The simulation, modeling and stability analysis of DC-DC Boost converter for Solar Electric system is done using space averaging technique in order to study its time domain, frequency domain and pole-zero domain analysis. A feedback controller for DC-DC boost converter is Designed to obtain constant output voltage of 24 V.A fuzzy logic controller is later used to control the output voltage of the boost converter. Simulation results show that fuzzy logic controlled boost converter has fast transient response, better steady-state response, and the proposed converter is less sensitive to load changes as compared to that of PID controller.

Introduction

Emerging need of renewable sustainable source of energy has resulted in advancement of numerous solar electric applications. DC-DC converters are considered to be of great economical importance in today's society, and are perhaps one of the few electronic circuits that are commonly used in switching power supplies. The solar energy conversion systems can be connected to a large electrical transmission grid, or to the storage or auxiliary energy supply[1].To obtain a stable voltage from an input supply (PV cells) that is higher and lower than the output, a high efficiency and minimum ripple DC-DC converter is required in the system for residential power production[1].

The voltage level from a solar input voltage is raised to a higher level for the applications which demands a higher voltage level. The simulation model of the converter uses the designed parameters for the voltage conversion. The demand for energy, particularly in electrical forms, is ever-increasing in order to improve the standard of living [2]. The dc-dc converters can be viewed as dc transformers that deliver to the load a dc voltage or current at a different level than the input source. This dc transformation is performed by electronic switching means, not by electromagnetic means such as in conventional transformers[2].Here, MATLAB simulation of the proposed converter provides stronger evidences about its stability, and the usefulness when applied to the solar electric systems. The block diagram of solar electric system is shown
In Figure 1.

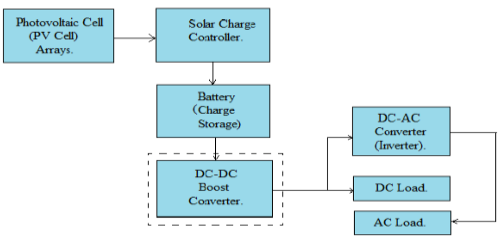

Fig.1. Block Diagram of Solar Electric System

Parameters used for Designing of DC-DC Boost Converter.

Boost Converter Simulation			
	Parameter	***Value***	***Unit***
1	Input Voltage(V_{in})	12	V
2	Output Voltage(V_0)	24	V
3	Switching frequency(f)	20	kHz
4	Duty Ratio(D)	0.5	-
5	Maximum Inductor Current(I_{Lmax})	4.50	A
6	Minimum Inductor Current(I_{Lmin})	0.30	A
7	Ripple (r)	0.00125	-

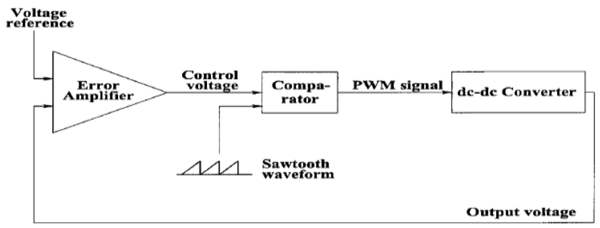

Fig.2. Circuit for closed loop PWM boost converter.

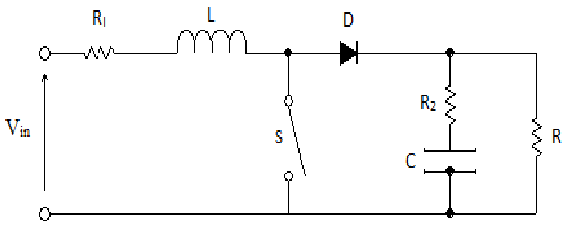

Fig.3. Circuit design of boost converter

State Space Averaging Technique

L = inductance in the circuit.
C = capacitance in the circuit.
D = duty cycle.
f = switching frequency.
R_I = parasitic resistance of an inductor.
R_2= parasitic resistance of a capacitor.

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V_{in}= input solar voltage to the converter.
L_b=boundary value for inductance.
C_{min}=minimum capacitance required for continuous conduction mode.

In the above circuits, S is the electronic high speed switch (that is supposed to be ideal), D the diode, C the capacitor, L the inductance, and the load , for simplicity, is taken to be ohmic and is denoted by the resistance R. When the switch S is in the on state, the current in the boost inductor increases linearly and the diode D is off at that time. When the switch S is turned off, the energy stored in the inductor is released through the diode to the output RC circuit.[2]

For Continuous Conduction Mode (CCM), the value of L and C should be greater than L_b (=62.5 micrometry)and C_{min}(=125 microfarad if ripple considered is 1%)respectively. Since it is assumed that the converter is operated in continuous conduction mode, two different systems must be considered. The state-space description of each one of these two systems is derived as given below.

The current flowing through an inductor and the voltage across the capacitor is taken as state variables for obtaining the state space model of dc-dc boost converter.

When Switch is on

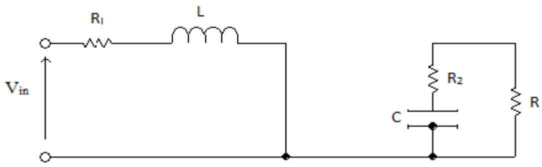

Fig.4. Configuration of the converter for S on.

The State Space Model Equation:
$X = A_1x + B_1V_{in}$.
$Y = C_1x$.

$$A_1 = \begin{bmatrix} -R_l/L & 0 \\ 0 & -1/C(R+R_2) \end{bmatrix}$$

$$B_1 = \begin{bmatrix} 1/L \\ 0 \end{bmatrix}$$

$$C_1 = \begin{bmatrix} 0 \\ R/(R+R_2) \end{bmatrix}$$

When Switch is off

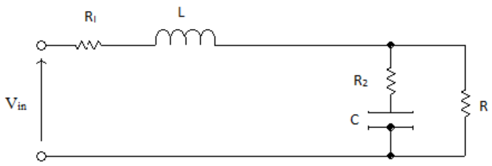

Fig.5. Configuration of the converter for S off.

The State Space Model Equation:
$X = A_2x + B_2V_{in}$.
$Y = C_2x$.

$$A_2 = \begin{bmatrix} -(1/L)(R_l + ((R R_2)/L(R+R_2))) & -R/L(R+R_2) \\ R/C(R+R_2) & -1/C(R+R_2) \end{bmatrix}$$

$$B_2 = \begin{bmatrix} 1/L \\ 0 \end{bmatrix}$$

$$C_2 = \begin{bmatrix} RR_2/(R+R_2) \\ R/(R+R_2) \end{bmatrix}$$

State-space averaging (Middlebrook andCuk, 1976) is one method to approximate this time-variant system with a linear continuous time-invariant system [5].Now, state-space descriptions are then averaged with respect to their duration of theswitching period. For D= 50 %using state space averaging technique we get the following matrices.[4]

$$A = \begin{bmatrix} (-R_l/L)-((R^* R_2)/(2^*L^*L(R+R_2))) & -R/(2^*L(R+R_2)) \\ R/(2^*C(R+R_2)) & -1/(C(R+R_2)) \end{bmatrix}$$

$$B = \begin{bmatrix} 1/L \\ 0 \end{bmatrix}$$

$$C = \begin{bmatrix} R R_2/2(R+R_2) \\ R/(R+R_2) \end{bmatrix}$$

MATLAB Simulink Model

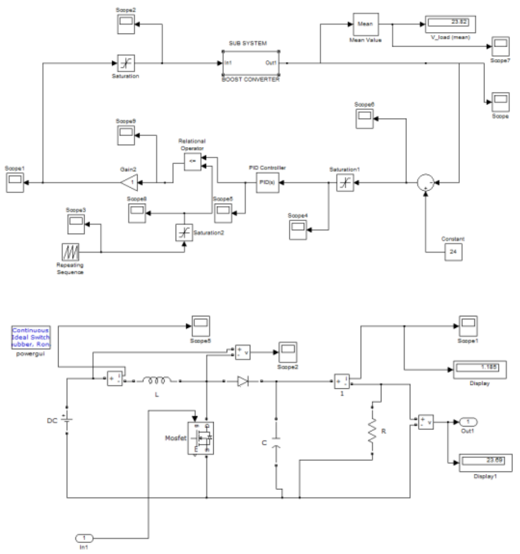

Fig.6. MATLAB Simulink Model

Simulated Waveforms

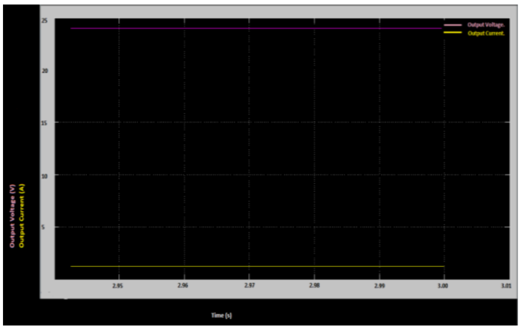

Fig.7. output Voltage waveform

Fuzzy Logic Control

Fuzzy logic works on experience of human knowledge being added in the controller. It is Robust in nature, gives better control characteristics and its usefulness is more.

Experimental analysis:

First a hardware model of closed loop dc dc converter was implemented and the following experimental data's were obtained:

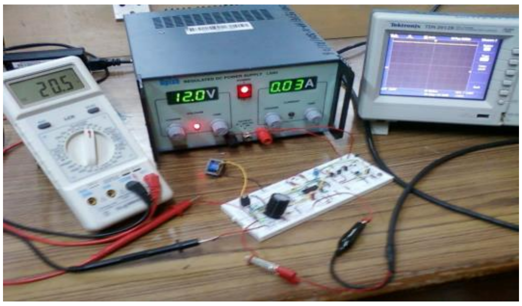

Fig.8.Closed loop Boost converter hardware model

Table II.Experimental data's

Input Voltage(Volts)	Duty cycle (%)	Output Voltage(volts)
12	10	13.6
12	20	14.9
12	30	17.6
12	40	19.9
12	50	23.4
12	60	30
12	70	39.8

The following fuzzy logic input and output membership plots were done in Matlab with the help of above experimental datas.

Fig.9. mamdani Input output blocks

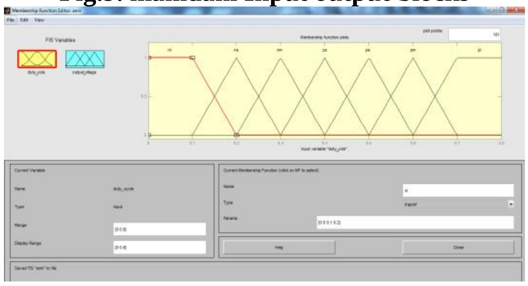

Fig.10.Duty ratio membership plot

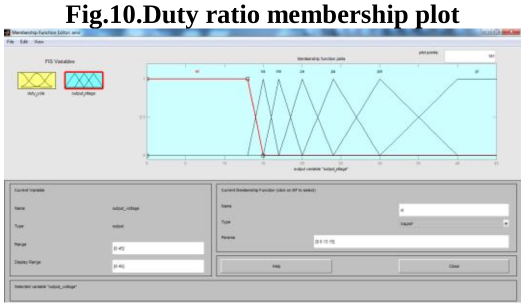

Fig.11 Output voltage membership plot

Practical Waveforms

Fig.12. Output Voltage at duty cycle of 50%.

By varying the pulse width of the gate signal, the duty cycle is changed and the output voltage at different values of duty cycle ratio is obtained using Fuzzy logic.

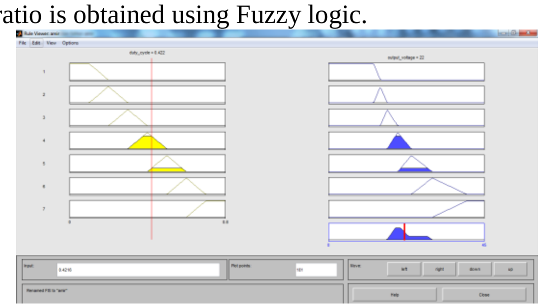

Fig.13. Output voltage at duty cycle of 42%

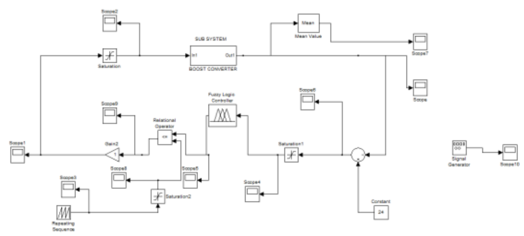

Fig.14. Simulink model using Fuzzy logic controller

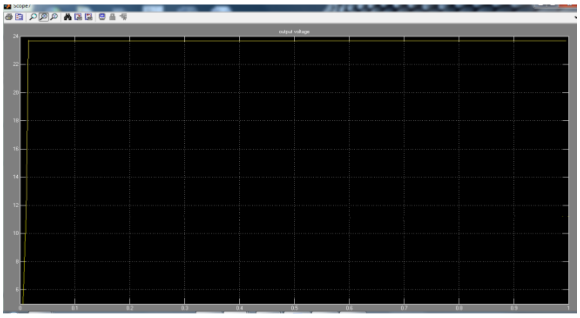

Fig.15.Output Voltage Waveform using Fuzzy controller

In the output waveform we can see that after using Fuzzy controller, the output waveform has improved i.e. the rise time has reduced and the peak overshoot has also been minimized.

The value of matrices obtained will be:

$$A=\begin{bmatrix} 26.71 & 6900 \\ 250 & -1000 \end{bmatrix} \qquad B=\begin{bmatrix} 13000 \\ 0 \end{bmatrix}$$

$$AB=\begin{bmatrix} (26.71*13000) \\ (13000*250) \end{bmatrix} \qquad |U|=\begin{vmatrix} B & AB \\ 13000 & (26.71*13000) \\ 0 & (13000*250) \end{vmatrix} \neq 0$$

Hence, the system is controllable.

$$|v| = \begin{bmatrix} C\text{^}T & A\text{^}T\ C\text{^}T \\ 0.12 & (26.7*0.12) \\ 0 & (250*0.12) \end{bmatrix} \neq 0$$

Hence, the system is completely observable.

Matlab Analysis

Time Domain Analysis:

Any system will exist only in the time domain. However response viewed in time domain can also be viewed in frequency domain or pole-zero domain which are used to explain excitation capability, decay of the noises, disturbances and sinusoids which affects the output. Here we can see an attainment of steady state value with zero overshoot. As there is no peaking observed in the step response of the above circuit, which attains a constant value with no transients in it.

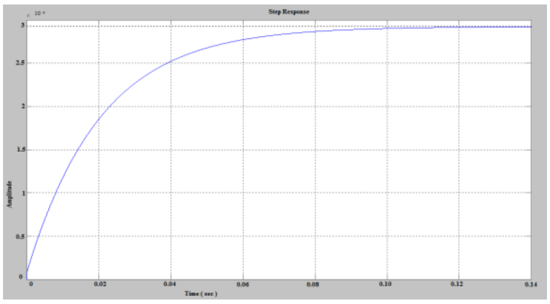

Fig.16. Step Response of the system

Pole-zero Domain Analysis:

Basically s-plane is the representation of the physical system that gives an idea about poles, location of poles, zeroes, location of zeroes of the system. In fact a pole in time domain is nothing but an exponential behavior which can be of increasing or decreasing in nature.[5]

The poles obtained are (-4.78e+7), (-2e+3) and the zero is (-2e+3). Since all the poles and zeroes lies on the left-hand side of the s-plane are negative and they represent the exponential decay mechanism such that any disturbances or unwanted excitations decays. This analysis gives an insight in dynamic and disturbance rejection behavior which cannot be obtained from another two described domain. It serves as a good aid to position the poles and zeroes such that at any disturbance/noise/rejection and decaying properties of the system can be planned and designed thereby any values of components, parameters can be chosen. A positive pole indicates growing mechanism instead of decaying leading system to an unstable state. Now how far the zeroes and poles lie away from imaginary axis will determine the features and characteristics of damping, decaying nature and all those issues which can be used to synthesize the circuit.[7]

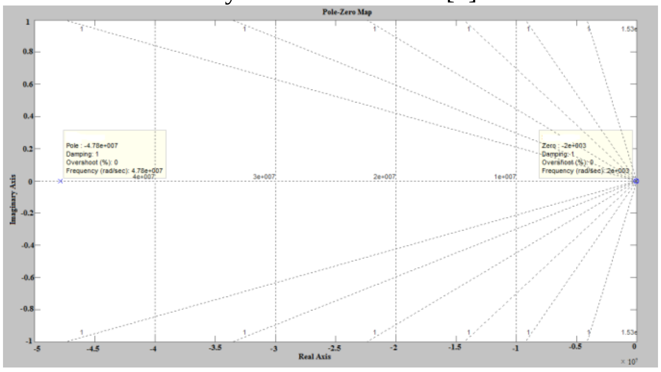

Fig.17. Pole-Zero Mapping

Frequency Domain Analysis:

The Decibel-Gain plotted against frequency and phase plotted against logarithmical scale of frequency concludes that the system analyzed above is stable with infinite gain and phase margin since the phase crossover point as well as gain crosses over point cannot be determined.

Phase crossover point in the bode plot is the point at which phase plot intersects with the -180° horizontal line. The frequency corresponding to the point of intersection is called phase crossover frequency.[6]

Gain cross over point in the bode plot is the point at which magnitude plot intersects with the0 dB line. The frequency corresponding to the point of intersection is called the gain crossover frequency.

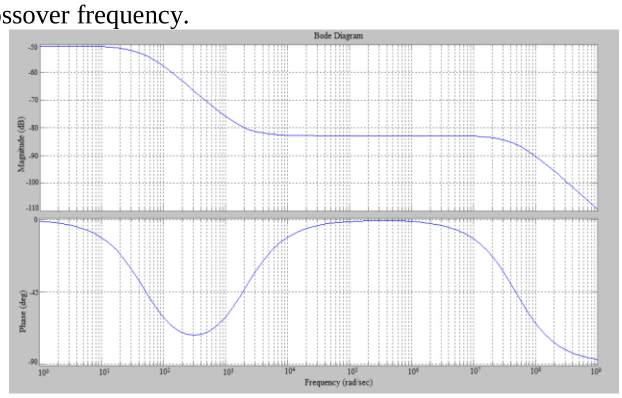

Fig.18.Bode plot

Conclusion

1. In case of a boost converter the output voltage ripple can be limited by the use of a larger filter capacitor in comparison to that in the buck-derived converters. The filter capacitor must provide the output dc current to the load when the diode D is

off. The minimum value of the filter capacitance that can be used is 125 microfarad (considering ripple as 1%).

The end result is that the value of L and C are much larger than those of a buck regulator. We have used high value of capacitance in order to reduce ripple in our system.[3]

2. From simulation we can found out that a higher frequency reduces the size of inductors for the same value of ripple current and filtering requirement.

3. Transfer function for the above system is

$$\frac{3415\,s + 6.825e06}{s^2 + 4.781e07s + 2.336e09}$$

4. Rouths- Hurwitz Stability Criterion: It is an algebraic procedure that provides information on the absolute stability of a LTI system using its characteristic polynomial.It was found that all the elements of the first column of the array were positive which indicated all the roots of the characteristic equation were locatedin the left half of s-plane. Thus, providing BIBO stabilility for our system.[8]

5. Eigen Values: The Eigen value obtained for our system was a negative real number which implies the system shall be driven back to its steady state value by an exponential decay mechanism.

6.Fuzzy controller is a better controller as compared to conventional PID controller.

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