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Original Research Article

AN INVESTIGATION ON SLIDING MODE CONTROLLER WITH FUZZY INFERENCE SYSTEM FOR A DC-DC CONVERTER

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Abstract—
This paper aims to design and simulate a pulse width modulating signal based on sliding mode controller for a DC-DC converter with fuzzy inference operating in continuous conduction mode. Solar panel with DC-DC converter fed to a DC load is controlled by the sliding mode controller. The sliding mode controller uses a sliding surface for generating the necessary pulses for the converter inference by fuzzy logic, which regulates the voltage at the load terminal. The fuzzy inference system with sliding mode controller used in this paper provides steady state condition under non-linear case of the system.

Keywords— DC-DC Power Conversion, POESLL Converter, Sliding Mode Controller, Fuzzy Logic Controller.

Introduction

DC-DC conversion technology has been developing very rapidly, and DC-DC converters have been widely used in industrial applications such as dc motor drives, computer systems and communication equipments. The positive output elementary super lift Luo converter is a new series of DC-DC converters possessing high-voltage transfer gain, high power density; high efficiency, reduced ripple voltage and current (1) However, their circuits are complex. An approach to positive output elementary super lift Luo converters implements the output voltage increasing in geometric progression with a simple prearranged structure have been introduced. These converters also effectively enhance the voltage transfer gain in power-law terms (1). Due to the time variations and switching nature of the power converters, their dynamic behavior becomes highly non-linear. The design of high performance control for them is a challenge for both the control-engineering engineers and power electronics engineers. In general, a good control for DC-DC converters always ensures stability in arbitrary

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operating condition. Moreover, good response in terms of rejection of load variations, input voltage variations and even parameter uncertainties is also required for a typical control scheme. The steady state and dynamic characteristics of these converters have been well (2).

The classical linear control methods have been applied on DC-DC converters with these equations. The variable structure control which is also as sliding mode control (SMC) is habitually appropriate to DC-DC converters with any level of complexity. The sliding mode control technique offers several advantages compared to traditional control methods: stability, even for large line and load variations, robustness, good dynamic response and simple implementation. Various studies in the application of SMC for DC-DC converters have been reported in the past several decades (3)-(4).

converter operation and smc

For the purpose of optimizing positive output elementary Super lift Luo converter dynamics, while ensuring correct operation in any working condition, a sliding mode controller is a more feasible approach.

Sliding mode control has been presented as a good alternative to the control of switching power converters [5], [11]-[12]. The main advantage over the classical control schemes is its insusceptibility to system parameter variations that leads to invariant dynamics and steady-state response in the ideal case.

Circuit Description and Operation

The positive output elementary super lift Luo converter is shown in Fig. 1. It includes dc supply voltage Vin capacitors C1and C2 inductor L1, power switch (n-channel) S, freewheeling diodes D1and D2 and load resistance R.

The principle of the sliding mode controller is to make the capacitor voltages VC1and VC2 follow as faithfully as possible capacitor voltage references.

In the description of the converter operation, it is assumed that all the components are ideal and also the positive output elementary super lift Luo converter operates in a continuous conduction mode. Fig. 2 and Fig. 3 illustrate the modes of operation of the converter [1].

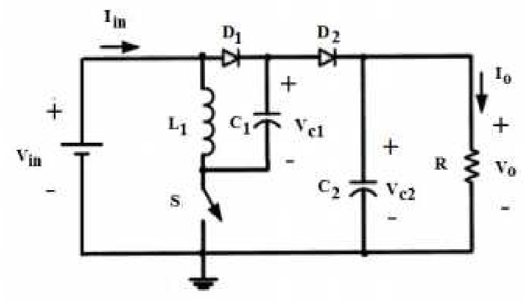

Fig.1. Positive output Elementary Super Lift Luo Converter

In Fig. 2 when the switch S is closed, voltage across capacitor C1is charged to V_{in}. The current iL_1 flowing through inductor L_1increases with voltage V_{in}.

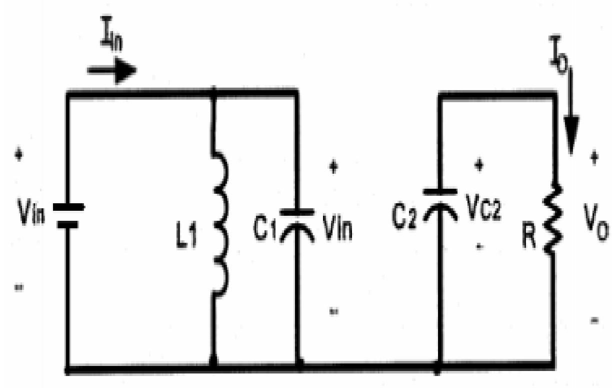

Fig.2. Mode 1 operation

In Fig. 3 when the switch S is closed, decreases with Voltage (Vo- $2V_{in}$).Therefore, the ripple of the inductor current iL_1.

$$\Delta_{iL1} = \frac{V_{in}}{L_1} dT = \frac{V_O - 2V_{in}}{L_1} dT$$

$$V_O = \frac{2-d}{1-d} V_{in} \qquad (1)$$

The voltage transfer gain is

$$G = \frac{V_O}{V_{in}} = \frac{2-d}{1-d} \qquad (2)$$

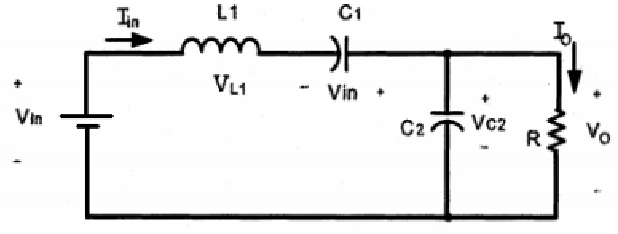

Fig.3.Mode 2 operation.

The input current is equal to (iL_1+ iC_1) during switching on and only equal to iL_1 during switching-off. Capacitor current iC_1 is equal to iL1during switching-off. In steady state, the average charges across capacitor C1 should not change.

$$i_{in-off}=i_{L1-off}=i_{C1-off}\ ,\ i_{in-on}=i_{L1-on}+i_{C1-on}$$

$$dT\,i_{C1-on}=(1-d)Ti_{C1-off} \quad (3)$$

If inductance $L_1$is large enough, iL_1 is nearly equal to its average current iL_1. Therefore

$$i_{in-off}=i_{L1}=i_{C1-off}\ ,\ i_{in-on}=i_{L1}+\frac{1-d}{d}\frac{i_{L1}}{d}$$

$$i_{C1-on}=\frac{(1-d)}{d}i_{L1} \quad (4)$$

and average input current

$$I_{in}=di_{in-on}+(1-d)i_{in-off}=i_{L1}+(1-d)i_{L1}=(2-d)i_{L1} \quad (5)$$

$$\frac{V_{in}}{I_{in}}=\left(\frac{(1-d)}{(2-d)}\right)^2\frac{V_o}{I_o}=\left(\frac{(1-d)}{(2-d)}\right)^2 R \quad (6)$$

The variation ratio of inductor current is

$$\xi=\frac{\Delta_{iL1/2}}{i_{L1}}=\frac{d(2-d)TV_{in}}{2L_1I_{in}}=\frac{d(1-d)^2}{2(2-d)}\frac{R}{fL_1} \quad (7)$$

The ripple voltage of output voltage is

$$\Delta_{vo}=\frac{\Delta Q}{C_2}=\frac{I_o(1-d)T}{C_2}=\frac{(1-d)}{fC_2}\frac{V_o}{R} \quad (8)$$

Therefore, the variation of output voltage is

$$\xi=\frac{\Delta_{vo}/2}{V_o}=\frac{(1-d)}{2RfC_2} \quad (9)$$

The state-space modeling of the equivalent circuit of (POESLLC) with state variables iL_1, V_{C1} and V_{C2} is given by

$$\begin{bmatrix}\frac{di_{L1}}{dt}\\ \frac{dV_{C1}}{dt}\\ \frac{dV_{C2}}{dt}\end{bmatrix}=\begin{bmatrix}\frac{1}{R_{in}L_1} & -\frac{1}{L_1} & -\frac{1}{L_1}\\ \frac{1}{C_1} & 0 & 0\\ \frac{1}{C_2} & 0 & -\frac{1}{RC_2}\end{bmatrix}\begin{bmatrix}i_{L1}\\ V_{C1}\\ V_{C2}\end{bmatrix}+\begin{bmatrix}\frac{V_{C1}+V_{C2}}{L_1}\\ -\frac{2i_{L1}}{C_1}-\frac{V_{C1}}{R_{in}C_1}+\frac{V_{in}}{R_{in}C_1}\\ -\frac{i_{L1}}{C_2}\end{bmatrix}\gamma+\begin{bmatrix}\frac{V_{in}}{L_1}\\ 0\\ 0\end{bmatrix}$$

$$\dot{\nu}=A\nu+B\gamma+C \quad (10)$$

Where R_{in} is internal resistance source which is not shown in the circuit but it is very small value, γ is the status of the switches; υ and ύ are the vectors of the state variables (iL_1, V_{C1}, V_{C2}) and their derivatives respectively.

Sliding Mode Controller

When good transient response of the output voltage is needed, a sliding surface equation in the state space, expressed by a linear arrangement of state - variable errors εi, the system response is determined by the circuit parameters and coefficients K1, K2 and K3. With a proper selection of these coefficients in any operating condition, high control robustness, steadiness and fast response can be achieved [7].

In theory, the sliding mode control requires sensing of all state variables and generation of suitable references for each of them. However, the inductor current reference is difficult to evaluate since that generally depends on load power demand supply voltage, and load voltage. To overcome this problem in implementation, the state variable error for the inductor current (iL_1-iL_{1ref}) can be obtained from feedback variable iL1by means of a high-pass filter in the assumption that their low-frequency component is automatically adapted to actual converter operation [8].

$$u=\begin{cases}u^+ & \text{for } S(x,t)>0\\ u^- & \text{for } S(x,t)<0\end{cases} \quad (11)$$

Thus, only the high frequency component of this variable is needed for the control. This high pass filter increases the system order and can heavily alter the converter dynamics. In order to avoid this problem, the cutoff frequency of the high-pass filter must be suitably lesser than the switching frequency to pass the ripple at the switching frequency, but high enough to allow a fast converter response.

The fundamental idea of SM control is to design first a sliding surface in state space and then the second is to design a control law direct the system state trajectory starting from any arbitrary initial state to reach the sliding surface in finite time, and finally it should come to a point where the system balance state exists that is in the origin point of the phase plane [9].

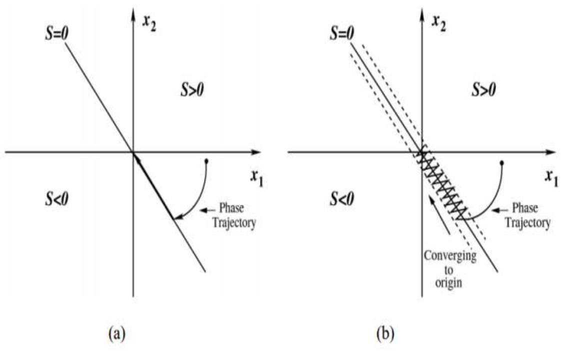

Fig.4: Phase Plot for (a) ideal SM Control (b) actual SM control

The sliding line (when it is a two variable SM control system in two-dimensional plane) divides the phase plane into two regions. Each region is specified with a switching state and when the trajectory arrives at the system equilibrium point, the system is considered as stable.

Switching frequency

In the ideal sliding mode at infinite switching frequency, state trajectories are directed toward the sliding plane and move exactly along it. A practical system cannot switch at infinite frequency. Therefore, a typical control circuit features a practical relay.

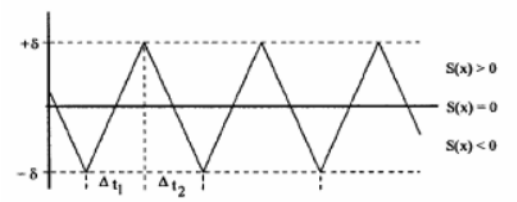

Fig.5. Waveform of S(X)

It is appealing to note that the switching frequency, inductor current ripple, and capacitor voltage ripple depend on the following: the control parameters, circuit parameters, reference voltage, output capacitor voltage $V_{C2}(t)$,and inductor current $iL_1(t)$ [10].

It is important to determine the circuit parameters and coefficients K1, K2 and K3 that agree with desirable values of maximum inductor current ripple, maximum capacitor voltage ripple, maximum switching frequency, stability and fast reaction for any operating condition

Fuzzy Logic Controller

Fuzzy logic has two dissimilar meanings. In a narrow sense, fuzzy logic is a logical system, which is an extension of multi valued logic. However, in a wider sense fuzzy logic (FL) is almost synonymous with the theory of fuzzy sets, a theory which relates to classes of objects with unsharp boundaries in which membership is a matter of degree. In this perspective, fuzzy logic in its narrow sense is a branch of FL. Even in its more fine definition, fuzzy logic differs both in concept and substance from traditional multi valued reasonable systems. What might be added is that the basic concept underlying FL is that of a linguistic variable, that is, a variable whose values are words rather than numbers.

S

S*

	N	Z	P
P	Z	PM	PB
Z	NM	Z	PM
N	NB	NM	Z

Fig.6.Rule Base of FSMC

In effect, much of FL may be viewed as a methodology for computing with words rather than numbers. Although words are inherently less precise than numbers, their use is closer to human instinct. Furthermore, computing with words exploits the tolerance for imprecision and thereby lowers the cost of solution.

The FIS Editor displays information about a fuzzy inference system. To open the FIS Editor, type the following command at the MATLAB prompt: Build Mamdani Systems (GUI) fuzzy. The FIS Editor opens and displays a diagram of the fuzzy inference system with the names of each input variable on the left, and those of each output variable on the right. The rule base of FSMC gives the preferred characteristic feature for the performance of the converter. The converter inference with fuzzy sliding mode delivers boosted output for the load terminal.

designing and simulation results

The system is designed for non-linear system characteristics, as the load and the internal converter parameters get altered in accordance with its performance. The performance should be of in nominal value even though the variation takes place due to the internal and external parametric changes. A converter is designed using the sliding mode controller to avail the needed output *characteristics of the system*

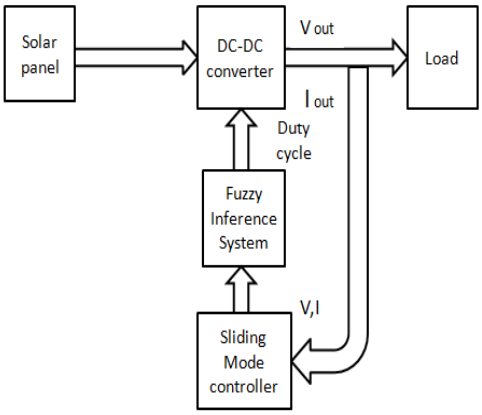

Fig.7. Block Diagram of the system

The system with sliding mode controller and fuzzy inference system is designed for the positive element super lift luo converter. The converter is designed to obtain a nominal value in all the non-linear case of the system. The converter switching frequency and the duty cycle is altered in order to obtain the converter output to be equal to the load variation without considering the internal losses that is taking place in the converter.

The sliding mode controller is designed to operate at infinite switching frequency .The infinite switching frequency is the condition that makes the sliding mode controller to operate within the sliding mode surface and the surface is defined to operate the state variables along the sliding plane. The sliding mode controller is designed to operate at infinite switching frequency which generates losses in the converter circuit .It has to be avoided so, that the converters switching frequency is predefined to perform the converter without losses. So the sliding plane is defined to perform the sliding operation and the controller operation.

Calculation of vc2

The output voltage is chosen to produce a variation of the duty cycle close to 0.5. The adopted value of the output voltage is 36 V which is in Table I,

A variation of the duty cycle between d_{min}= 0.3 and d_{max}= 0.56 is expected. Finally V_{C2max}= 36.5V.

Determination of Ratio K1/ L1

Substituting V_{in}, $V_{C1\ ref\ (max)=}$ $V_{C1(max)}$and δ= 0.3 one obtains K1/ L_1=6666.67.

c. *Determination of Ratio K2/ C_1 and K3/ C_2*

Taking iL_1ref = iL_1 (max)= 2.353 A, one obtains 1208 < K2/ C_1< 248433 and 1208 < K3/ C_2 <248433.

There are some degrees of self-determination in choosing the ratio K2/ C1and K3/ C2. In this controller, the ratio K2/ C1and K3/ C2 is a tuning parameter. It is recommendable to choose the ratio K2/ C1 and K3/ C2 to agree with required levels of stability and response speed. The ratio K2/ C1and K3/ C2 is chosen by iterative procedure (i.e the ratio is modified until the transient response is satisfactory), and it is verified by simulation. The final adopted value is, K2/ C1and K3/ C2=7248..

D. Calculation of L1

The utmost inductor current ripple is chosen to be equal to 15 % maximum inductor current, and L_1= 100 µH which is obtained.

E. Calculation of C1and C2

The maximum capacitor ripple voltage ΔVC_{1max} and ΔVC_{2max} is chosen to be equal to

0.5 % maximum capacitors voltage, and $C_1= C_2 = 30\ \mu F$ which is obtained.

F. Values of the coefficients K1, K2 and K3

Having decided on the values of the ratio K1/L1and inductor, the value of K1 is unswervingly obtained (K1=0.667). Similarly the K2 =K3= 0.217 is computed using the ratio K2/ $C_1$and K3/ $C_2$and the C_1, C_2.

The variable error of iL_1 and VC_1, VC_2near zero. The system response is determined by the circuit parameters and coefficients K1, K2 and K3. With a proper selection of these coefficients in any operating condition, high control sturdiness, stability, and fast response can be achieved.

The system is simulated using the MAT Lab software. The software provides the necessary tool boxes to perform the task. The DC-DC converter used in this paper is designed using the MAT Lab software.

The design process involves analysis of the circuit in accordance with the variation and the changes happening in the converter circuit due to the conventional load variation and internal circuit changes

The simulation of the system with a sliding mode controller has been simulated and the converter is designed for the load variation and the internal parameter variation.

TABLE I.

SYSTEM PARAMETER SPECIFICATIONS

S.NO	LABELS	SPECIFICATION
1.	L	1500*10^-6
2.	C_1	100*10^-6
3.	C_2	100*10^-6

The system has the parameters like capacitor, inductor, diode and Mosfet and a load resistor. The positive element super lift luo converter is designed with a sliding mode controller.The simulation shows the improved output from the given input value. The simulation is performed as such in closed loop for the non-linear uncertainties of the system.

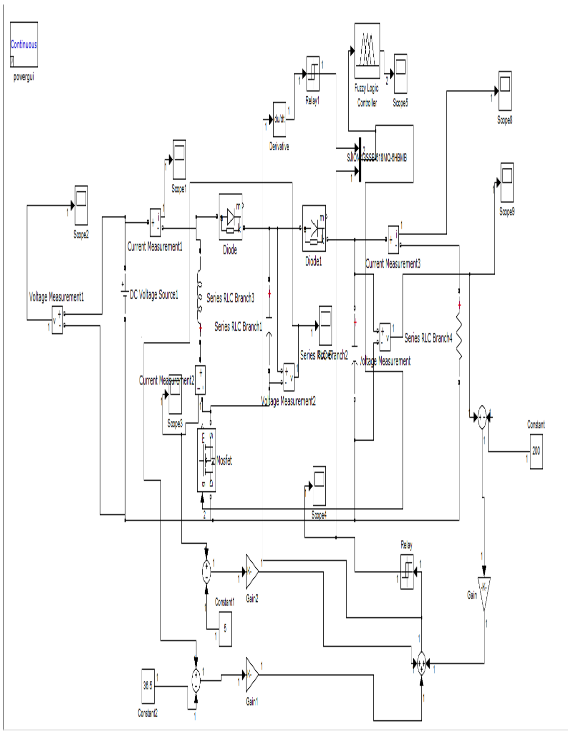

Fig.8. Simulation Model of FSMC with Positive Output Super Lift Luo Converter.

The Sliding mode controller is insensitive to parameter variations and External Disturbances. The nature of the controller is to ideally operate at an infinite switching frequency. The Sliding Mode Controller provides a systematic approach to the problem of maintaining stability. The non-linear characteristic of the system is adjusted by the use of the sliding mode controller. The system or a converter with uncertainties due to the converter and the external load variations causes problem. This has been adjusted to maintain at a nominal value whatever may be the system variation.

The sliding mode controller has been proposed to perform the variation alteration to a nominal value by the phase trajectory specification and making it approach to the error zero. The sliding surface is defined to perform the state variables approach to zero state using the state variable trajectory to approach to the terminate state.

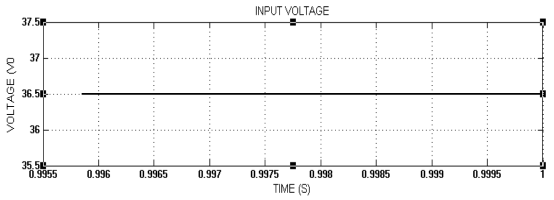

Fig.9.Input voltage

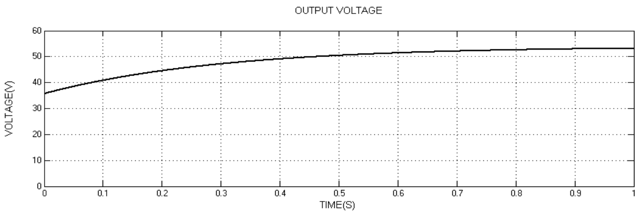

Fig.10.Output Voltage

The input of the converter is said to be at 36 V and is shown in fig.10. The converter is designed to adjust the output of the voltage to the nominal value of the load. The converter is designed to tackle the converter uncertainties and losses present in it .The converter variation is made to handle the output voltage.

The sliding mode controller is used to perform the closed loop operation in any non-linear condition. Even though, the system suffers losses from the converter losses and the system suffers from the non-linear load variations. The output of the system gets stabilized in all system non-linear variations .Thus, the load is met with a nominal stable value in all conditions.

The output from the converter is obtained by the closed loop operation of the controller. The reference value is given as input to the controller. And for the respective given reference value the output gets altered and the load is supplied with its required nominal voltage.

Hardware Designing

The hardware for the POESLLC is designed using IN4001 Diode, IRF840 Mosfet with the capacitor and Inductor values given as per the Table .I Specifications. A Microcontroller with the Sliding Mode and Fuzzy inference System coding is embedded into it which generates the gate pulses for the Mosfet to perform the boost operation. The Output obtained from it is of the voltage range 50 v.

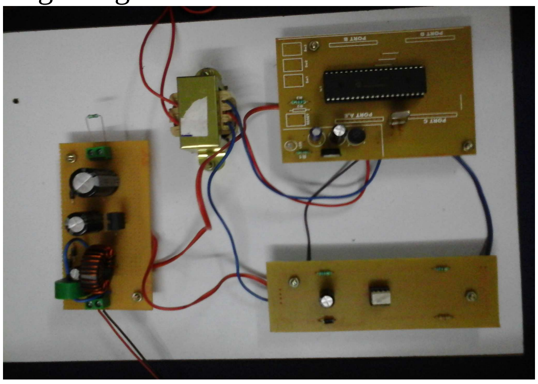

Fig.11. Hardware Circuit

The load variation uncertainties is taken as feedback to the controller and the controller performs the error correction, Which turn produces the necessary pulse turn ON signals to the gate terminal of the Mosfet and thereby obtains a stable output from the converter.

Conclusion

The positive output elementary super lift Luo converter (POESLLC) performs the voltage conversion from positive source voltage to positive load voltage. Due to the time variations and switching nature of the power converters, their dynamic behavior becomes highly non-linear. This paper has successfully demonstrated the design, analysis, and suitability of Fuzzy Logic based sliding mode controlled positive output elementary super lift Luo converter. The simulation based performance analysis of a Fuzzy Logic based sliding mode controlled positive output elementary super lift Luo converter circuit has been presented along with its state space averaged model. The Fuzzy Logic based SMC scheme has proved to be robust and its triumph has been validated with load and line regulations and also with circuit components variations. The positive output elementary super lift Luo converter with FSMC thus claims its use in applications such as computer peripheral equipment, switch mode power supply and industrial applications, especially for high voltage projects etc.

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