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# Implementation of Fuzzy Sliding Mode Control for Negative output Superlift Luo Converter

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***Abstract* - Standalone power systems play a vital role in developing remote units for various networks. These units require high negative DC supply voltages. One such converter known as Negative Output Superlift Luo Converter (NOSLC) is discussed in this paper. NOSLC is a high gain converter whose output increases in geometric progression. These DC-DC converters produce a lot of non-linearities due to its component characteristics while operating in the open loop mode. To meet the load demands and to overcome the non-linearities, a suitable controller should be implemented. This control approach is made feasible in this paper by integrating fuzzy technique with Sliding Mode Controller (SMC) known as FSMC. The proposed controller overcomes the phenomenon of chattering, reduces the settling time and provides good dynamic response compared to the classical SMC. Simulation studies are carried out in MATLAB/SIMULINK. The performance of fuzzy, sliding mode and FSMC are compared for NOSLC. A prototype of NOSLC with the proposed controller is implemented and the simulation results are verified experimentally.**

**Index Terms: NOSLC; fuzzy controller ; sliding mode controller; fuzzy sliding mode controller**
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## I. INTRODUCTION

This Switched mode power converters for industries require high efficiency and high conversion gain to handle large input current and sustain high output voltage stress. Various topologies of high gain converters are discussed in the literature. [1]. But this paper focuses on a Negative Output Superlift Luo Converter (NOSLC) as it provides high-voltage transfer gain, high power density, high efficiency and

reduced ripple voltage and current. But the main problem with the DC-DC converters is that their output varies against variation in the supply and load side.

In order to meet the load demands and also the non-linearities produced due to the circuit characteristics, a proper controller should be designed. Conventional controllers like P, PI, and PID play a significant role but supports only linear systems [2]. Therefore, the significance of non-linearity is overcome with the introduction of sliding mode controller [3]. But again SMC introduces noise and suffers from switching frequency variations. So, a fuzzified SMC (FSMC) is proposed in this paper which reduces the unwanted noise with its intelligentrule framing approach, provides better stability and faster dynamic response. The performance of the FSMC is compared with the conventional fuzzy and SMC. The proposed FSMC iimplemented in PIC microcontroller for NOSLC and the output is stabilized against load variation which gives better start-up behaviour and provides robustness to disturbances. The simulation results are verified practically.

The modelling of NOSLC is explained in section-II with its equations. The fuzzy control of NOSLC is discussed in section- III and the SMC control is depicted in section IV.The drawback of fuzzy and SMC is overcome by the FSMC technique which is explained in section-V followed by hardware implementation in section-VI and conclusion in section VII.

## II. OPERATION OF NOSLC

The output voltage of NOSLC increases in progressive range.i.e.ten to hundred times the input voltage. [4]The conversion gain is high with reduced output voltage ripple and also produces a boosted negative output voltage which plays a significant role in various sectors. The circuit diagram of the NOSLC is shown in Fig.1.The circuit consists of a MOSFET switch S1, Inductor L1, Diodes D1, D2, Capacitors C1, C2 and load resistance R. Equation(1) shows the geometric progression rise of the output voltage with ‘n’ representing the level of rise. Further lift of the voltages can be obtained by increasing the value of ‘n’ to 2, 3 and so on.

The voltage transfer gain is,

$$Vo = \frac{2-k}{1-k} - 1^{n-1}(Vin) \qquad (1)$$

The variation ratio of inductor current iLl is,

$$\xi = \frac{\Delta i_{L1}/2}{i_{L1}} = \frac{D(1-D)TV_{in}}{2L_1 I_0} = \frac{D(1-D)}{G_1}\frac{R}{2fL_1} \quad (2)$$

There are two modes of operation in NOSLC.

Mode- I is the switch on and mode II is the switch off mode. During mode I, the switch S1 is turned on and the current flows through the inductor L1 and capacitor C1 gets charged. The capacitor C1 charges faster than inductor thus forward biasing the diode D1.Thus charge gets stored in inductor L1 and capacitor C1. The load current is maintained constant by the discharging capacitor C2.

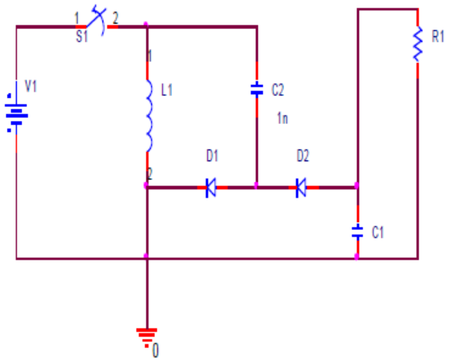

Fig. 1 .Circuit diagram of NOSLC

The energy stored in the capacitor C2 during the previous cycle is transferred to the load.During mode-II, the switch S1 is turned off. When the switch is open, the energy stored in the inductor L1 and the capacitor C1 gets transferred to the load. With this a high boosted output voltage is obtained across the load and therefore NOSLC is referred as high gain converter.

### *A.CONTROLLERS FOR NOSLC*

High gain DC-DC converters are employed for battery charging, solar PV systems, fuel cells and telecommunication sectors.But these converters under open loop condition exhibit poor load and line regulation. Moreover, the dynamic response of the converter will be sluggish. To improve the above mentioned parameters and characteristics, this paper discusses the three types of nonlinear controller namely, fuzzy logic controller, sliding mode controller and fuzzy sliding mode controller. These feedback controllers are designed and implemented for the negative output Luo converter.The proposed non-linear controllers are reported to give an excellent transient and steady-state response [5].In this paper, more emphasis is given to the dynamic parameters of the system like rise time, settling time, peak overshoot and steady state error. The performance of the proposed nonlinear controllers is compared and their results are verified.

## III. DESIGN OF FUZZY CONTROL OF NOSLC

This section deals with the fuzzy logic controller (FLC) for NOSLC. The fuzzy non-linear controller is designed based on the expert understanding [6-7] which portrays the rule frame of fuzzy structure and its results.

Fig 2 shows the fuzzy control of NOSLC.The output voltage of NOSLC is measured and compared with the reference signal. The error and change in error is given as an input to the fuzzy control block and the variation in the duty ratio is measured. This duty ratio is predicted with the rules framed as depicted in the table 1.The rule calculation is as follows.

$$\text{Error (e)} = Vref - Vo \qquad (3)$$

Here the range lies between -1 and 1.

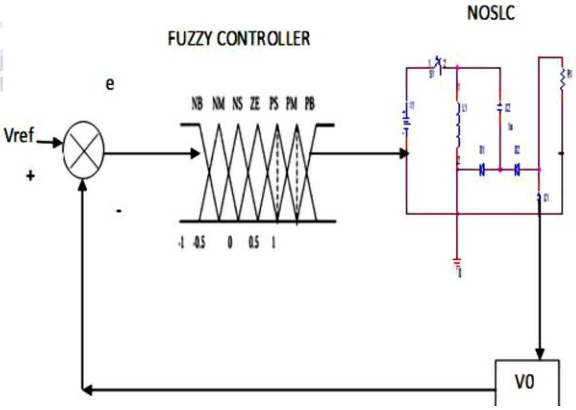

Fig. 2 .Schematic of Fuzzy with NOSLC

$$\text{Change in error (Ce)} = ek - ek - 1 \qquad (4)$$

The range for Ce and change in duty ratio dk lies between -1 and 1.

If e is NL (negative large), i.e., $ek$ = -1 and Ce is NS(negative small) i.e., Ce= -0.5 then $ek-1$ = -0.5

Since the error is increased when compared with the previous error, the duty cycle should be large enough so, dk = NL (negative large).This is how the rule table is formed as shown in table I.

Fig.3 represents the simulink model of fuzzy controller implemented for NOSLC. [8] The output voltage is measured and compared with the reference thereby generating error which is given as one of the input to the fuzzy block and change in error is predicted which is given as the other input to the fuzzy block. The output obtained is the desired duty ratio. Fig 4 shows the error (e) and change in error (de) given to FLC mamdani block. Fig 5 shows the membership values that lie between the range -1 and 1 which is depicted with the framed table values. Fig 6 shows the fuzzy waveforms of NOSLC. For an input of 12V, it shows an output of -36V and the voltage across the capacitor C1 is found to be -11V. Fig 7 shows the surface plot of fuzzy function showing the relation between input and output.

*TABLE I. RULE TABLE FOR FUZZY CONTROLLERS*

| e / Δe | NL | NS | Z | PS | PL |
|---|---|---|---|---|---|
| Duty ratio | | | | | |
| NL | NL | NL | NL | NS | ZE |
| NS | NL | NL | NS | ZE | PS |
| Z | NL | NS | ZE | PL | PS |
| PS | NS | ZE | PS | PL | PL |
| PL | ZE | PS | PL | PL | PL |

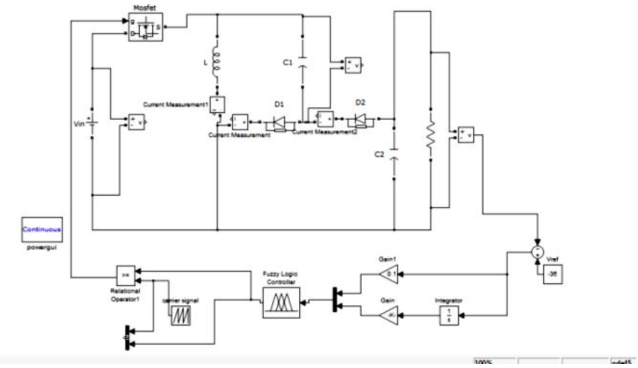

*Fig 3. Fuzzy control of NOSLC*

## IV.DESIGN OF SLIDING MODE CONTROL OF NOSLC

The objective of the SMC based NOSLC system is to make the passive components follow their reference values.So,the capacitor voltage and the inductor current is measured and compared with its reference and the error is multiplied with their respective gains to attain the duty ratio of the switching pulse. Thus the regulation of the output voltage is obtained with the variation in the duty ratio.

A sliding surface equation in the state space can be expressed by a linear combination of state-variable errors can be given by [9-10].

$$S=(i_{L1},V_{C1},V_{C2})=K_1\varepsilon_1+K_2\varepsilon_2+K_3\varepsilon_3 \quad (5)$$

$$\begin{aligned}\varepsilon_1 &= i_{L1}-i_{L1ref}\\ \varepsilon_2 &= V_{C1}-V_{C1ref}\\ \varepsilon_3 &= V_{C2}-V_{C2ref}\end{aligned} \quad (6)$$

Where coefficients $K_1$, $K_2$ and $K_3$ are proper gains, $\varepsilon_1$is the feedback current error, $\varepsilon_2$and $\varepsilon_3$ is the feedback voltage error. By substituting (6) in (5) we get,

$$S=(i_{L1},V_{C1},V_{C2})=K_1(i_{L1}-i_{L1}ref)+K_2(Vc_1-Vc_1ref)+ \quad (7)$$
$$K_3(Vc_2-Vc_2ref)$$

'S' decides the switching state as on and off. The summation of the parameter values of inductor and capacitor is taken and compared with the comparator to generate the switching pulse which is highly predicted by 'S'.

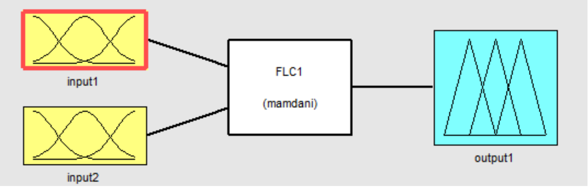

*Fig. 4 Error and change in error to fuzzy*

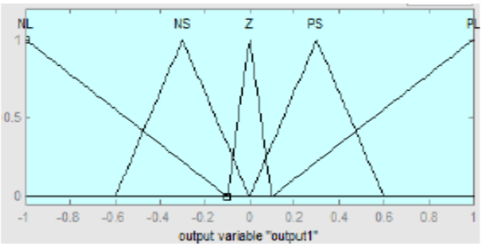

Fig 5. Membership values of fuzzy control block

Sliding mode control is obtained by means of the following feedback control strategy, which relates to the status of the switch with the value of S (x).[11].

$$Y = \begin{cases} 0, \ for\ S(x) > 0 \\ 1, \ for\ S(x) < 0 \end{cases} \qquad (8)$$

Fig 8 depicts the simulink model of sliding mode control for NOSLC. The generation of duty ratio is obtained by sensing the current and voltage parameters of NOSLC.Thus the regulation of the output voltage is obtained with the generated duty ratio.

Fig 9 shows the waveforms of sliding mode control. The output voltage is shown as -36V and rise time is found to be 0.0009s and the peak and settling time is found to be 0.0025s.Though it is same as that of fuzzy control, it offers a good dynamic control. The effect of chattering is maximum and so the fuzzy SMC is implemented. [12].

## V. FUZZY SLIDING MODE CONTROL OF NOSLC

In order to overcome the phenomena of chattering that exists in SMC, a fuzzy SMC has been proposed in this paper. [13- 14]. Fuzzy is an intelligent approach for uncertain systems. It is also a type of variable structure control. To bring a robust control, SMC parameters are fuzzified and the control logic is implemented. This again brings a reduction in the chattering and instability in the output. Here the FSMC can be explained with the concept of fuzzyfying SMC parameters using a stability approach.

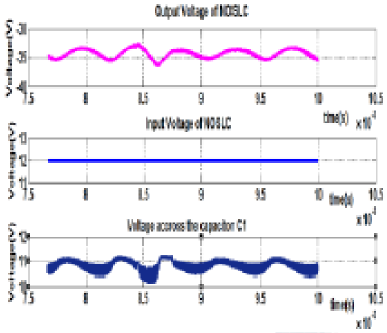

*Fig 6 Fuzzy waveforms of NOSLC*

It defines a sliding surface ‘S’ and the reach of the surface is highly obtained with the rule frame technique in fuzzy. The rule frame logic brings a control in the duty ratio ‘D’ of the switching pulse of the converter thereby maintaining steady state output.The FSMC satisfies the condition of lyapnov
stability which is given by
S * dS < 0 (9)

Where dS is the derivative of S.The duty cycle increase and decrease is obtained only by S and dS. The inductor current and the capacitor voltage is measured and compared with its references to generate the errors ξ1 and ξ2 .The sliding surface equation is formed only with the generated errors which is given below.
S= k1 ξ1 + k2 ξ2 (10)

Where k1 and k2 are the respective error gains. This slidings urface and its derivative acts as an input to the fuzzy block thereby generating the required duty ratio for the converter. Thus the fuzzy rule table II forms the controlled duty ratio for the converter.

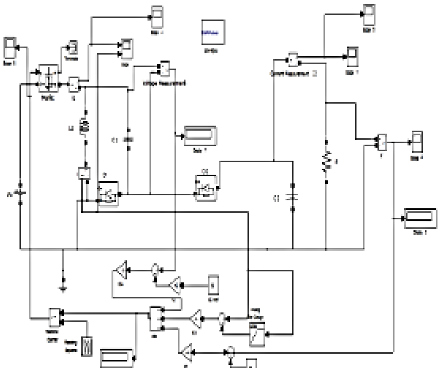

*Fig 8.Sliding mode control of NOSL*

*TABLE II. RULE TABLE FOR FSMC*

| e /Δe | Z | PS | PL |
|---|---|---|---|
| Duty ratio | Duty ratio | | |
| NL | NL | NS | ZE |
| NS | NS | ZE | PS |
| Z | ZE | PL | PS |
| PS | PS | PL | PL |
| PL | PL | PL | PL |

These control signals are assigned with five values as negative big, negative small, zero, and positive big, positive small. With respect to error, change in error to the fuzzy block, one of the control signals gives the desired duty ratio thereby maintaining the output to a steady state value. Fig 10 depicts the FSMC control of NOSLC in Simulink. It shows that the inductor current and the capacitor voltage is sensed and matched with the reference values by multiplying with the respective gains .These values are again fuzzified and compared with the repeating sequence to generate the required switching pulse of the converter. This helps in regulating the output voltage. The waveforms of fuzzy sliding mode control of NOSLC is shown in the Fig.11.It shows a good dynamic control with its response settling at a faster rate of 0.0015s.and the chattering is highly reduced in the integrated approach compared to fuzzy and sliding mode control.

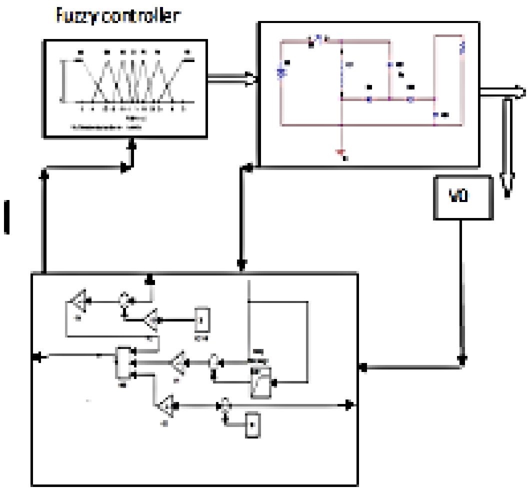

*Fig 10. Fuzzy sliding mode control of NOSLC*

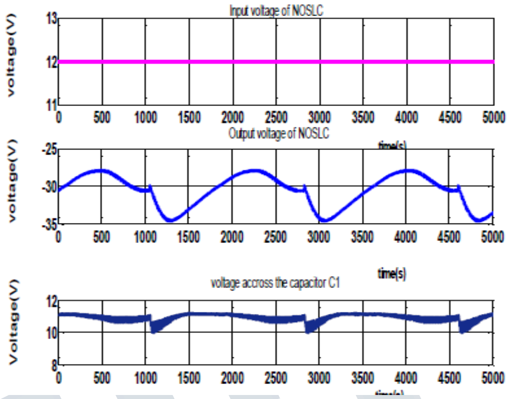

*Fig 11. Waveforms of FSMC of NOSLC*

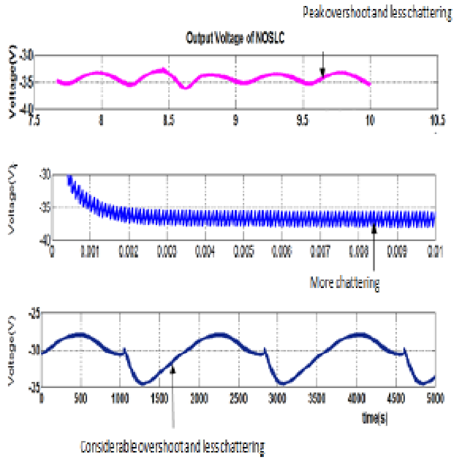

*Fig 12 represents the analysis of the output waveforms of all*

## VI. HARDWARE IMPLEMENTATION

This section deals with the hardware implementation of FSMC of NOSLC.Here the FSMC is digitally implemented using a microcontroller PIC 16F877A. Initially for a load of 330Ω as shown in fig 13, the output voltage is measured and the duty ratio is found to be 0.7.Again for a load change to 2.2K Ω, the output voltage is measured and the change in duty ratio is found to be 0.2.Thus the stabilized output voltage of - 36.5V is brought through the FSMC control with a change in duty ratio for varying load conditions.

**TABLE III. COMPARATIVE ANALYSIS OF CONTROLLERS FOR NOSLC**

| Parameters | Open loop output of | Closed loop control | | |
|---|---|---|---|---|
| | | Fuzzy | SMC | FSMC |
| Output voltage(V) | -36 | -35.5 | -35.5 | -35.5 |
| Peak overshoot(V) | -18.5 | -25.5 | -2 | -15.5 |
| Rise time(s) | 0.0003 | 0.00045 | 0.0009 | 0.0003 |
| Peak time(s) | 0.0005 | 0.00056 | 0.0025 | 0.0005 |
| Settling time(s) | 0.003 | 0.002 | 0.0025 | 0.0015 |

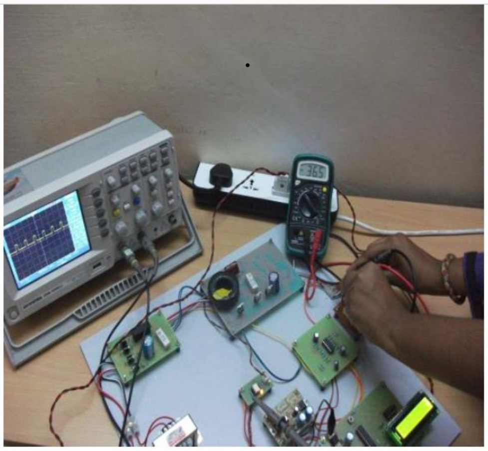

**Fig 13.**NOSLC with an output of - 36.5V

## VII. CONCLUSION

This paper has discussed the three different types of controllers namely fuzzy, SMC and FSMC for NOSLC and has shown that FSMC to be one of the suitable one for a better dynamic response. Moreover, from the results, it is obvious that the FSMC produced less chattering with a desirable overshoot in its output compared to fuzzy and conventional SMC technique. With the proposed FSMC applied to NOSLC, a prototype has been successfully developed and tested

## REFERENCES

[1] Luo F.L,"Relift converter,Design ,test, simulation and stability analysis"Electric Power Applications,IEE Proceedings,pp 315-325,IET, 145 (4), (1998).

[2] J.C.Basilio ; S.R.Matas"Design of PI and PID controllers with Transient Performance Specification",pp 364-370,IEEE transactions on Education,45(4),(2002).

[3] Ciccarelli ;Lauria D "sliding mode control of Bidirectional DC-DC converter for Supercapacitor Energy Storage Applications, Power electronics. Electrical drives Automation and motion,. SPEEDAM, pp1119-1122, June 14-16,(2010).

[4] Fang Lin Luo; Hong Ye, Negative Output Super-Lift Converters, IEEE transactions on power electronics,pp 1113-1121, 18 (5) (2003).

[5] LipingGuo,john;Y.Hung ;R.M.Nelms"Digital implementation of sliding mode fuzzy controllers for Boost converters"Applied power electronics conference and exposition,APEC '06,twenty first annual IEEE,pp1424- 1429, 4,(2006).

[6] C-F Hsu; I.F.Chung; C.M.Lin; C.Y.Hsu" Self-regulating fuzzy control for forward Dc-Dc converters using an 8-bit microcontroller"IET power electronics,pp 1-13,2(1),(2009)

[7] Ibrahim sefa; Necmi altin; Saban ozdemir,"DSPACE based fuzzy logic controlled boost converter",Electronics and Computer science,Scientific Bulletin,pp 36-41,(8)(2)(2008).

[8] T.Balamurugan;S.Manoharan,"Fuzzy controller design using soft switching boost converter for MPPT in hybrid systems"International Journal of Soft Computing and Engineering,pp 87-94,(2)(5)(2012).

[9] K.Ramash Kumar; Dr.S.Jeevanathan,"Design of sliding mode control for Negative output superlift luo converter operated in continuous conduction mode",Communication control and computing technologies,ICCCCT-10,7-9 Oct,IEEE international conference,pp 138- 148,(2010)

[10] P.F.Donoso-Garcia; P.C.Cortizo; B.R.de Menezes; M.A.Severo Mendes,” Sliding mode control for current disribution in parallelconnected DC-DC converters.IEEProc-Electr Power,145(4)(1998)

[11] Mahdavi, A Emadi; H.A. Toliyat, "Application of State Space Averaging Method to Sliding Mode Control of PWM DCDC Converters," Industry Applications conference,5-9 Oct,Vol 2,pp 820- 827.IEEE Industry Applications Society Annual Meeting New Orleans, October (1997).

[12] Y. B. Shtessel; A S. 1. Zinober; L. A. Shkolnikov, "Sliding mode control of boost and buck-boost power converters using the dynamic sliding manifold," International Journal of Robust and Nonlinear Control, 13(14),pp 1285-1298,July( 2003).

[13] smc-f-Jinhui zhang”.Robust Adaptive Sliding-Mode Control for Fuzzy Systems With Mismatched Uncertainties” pp 700-711,IEEE Transactions on fuzzy systems,18(4) (2010).

[14] J.Matas,L.G; de Vicuna,o.Lopez; M.Lopez; M.Castilla”Discrete sliding mode control of a Boost converter for output voltage tracking” power electronics and variable drives conferernce,pp 351-354,IEE conference,Publication no 475,IET,September (2000).