Fuzzy Logic Controller on Positive Output KY Voltage Boosting Converter

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Abstract—The importance of the high voltage gain, non-isolated, voltage-boosting converters is unquestionable in recent days. Among the diversified variety of such converters Positive Output KY Voltage Boosting Converter (POKYVBC) has merits such as low output voltage ripple in the order of few mV, fast transient response and settling time and larger voltage conversion ratio while operating in Continuous Conduction Mode (CCM). The challenging part of a power converter system is designing feedback controller to control in steady state and transient state. This paper focuses on design, analysis, simulate and implement Proportional-Integral-Controller (PIC) and Fuzzy Logic Controller (FLC) for POKYVBC. First the controllers are designed and performance simulated in MATLAB-Simulink software and then corroborated through experiments on the 28V output prototype POKYVBC.

Keywords — Positive output KY voltage boosting converter, fuzzy logic controller.

I. INTRODUCTION

A rough survey concludes that there have been more than 500 types of DC/DC converters developed in the past six decades while its basic categories include Buck converter, Boost converter and Buck-Boost converter. All above variations were developed to meet the requirements of specific applications [1]-[3]. The evolutionary classification of DC-DC converters has been done only after 2001 and one such systematic classification clusters them into six generations with their family tree for the history of seven decades. KY boost converter is a recently developed by K. I. Hwu and Y. T. Yau [4]-[5]. This converter operates in continuous conduction mode with low output voltage ripple in the order of few mV, fast transient response and settling time yielding larger voltage conversion ratio. The mandatory requirements of any power conversion systems are reduced components, smaller size, lower weight, lower cost, higher efficiency, higher reliability, lower switching stresses, wide conversion range, improved supply and load side performances etc.

The field driven performance requirements such as the larger voltage gain, huge power density, and decreased ripples in load voltage and inductor current imposed converter topologies and screwed the research direction. In the open loop system, the structure and the switching strategies contribute to achieve the objectives. In the closed loop systems the feedback controller has to take the responsibility. The DC-DC converter system is a complex structure, which works in different modes in their operating cycle, where the participating switches and components for every mode are unique. The fundamental working in any mode and the transition between modes are variable structure control in nature. Hence it necessitates an effective robust control approach with a goal of designing a controller and confirming stability in every working stage of the converter viz. initial start-up, dynamic responses (line and load variations), and the effect of component variation etc [6]-[7].

The design of a Fuzzy Logic Controller (FLC) using voltage output as feedback has been detailed for significantly improving the dynamic performance of boost dc-dc converter by using MATLAB@Simulink software [8]. A comprehensive study of different types of PID-like fuzzy logic controllers, such as fuzzy-P, fuzzy-PD, fuzzy-PI, and fuzzy PID, for application to DC-DC converters has presented [9]. A Variable Structure Fuzzy Logic Controller (VS-FLC) is proposed in this paper to overcome these disadvantages of fuzzy-PI controllers. A FLC controlled buck-boost DC-DC converter for solar energy-battery systems has been presented. General design of a FLC, based on Matlab/Simulink is performed [10]. This design compared with Proportional Integrated (PI) controller. The complete control system has been developed, analyzed, and validated by simulation study. Performances have then been evaluated in detail for different study conditions. The development and control of buck fed buck converter topology for high current application has been discussed [11].
For high current application like DC welding, single converter structure may cause complete system failure if the semiconductor switch fails. Hence, to improve reliability, parallel DC-DC converter structure is proposed. This arrangement ensures load sharing between the converters when operated in closed-loop mode. Simulation results obtained from the closed-loop configuration with a conventional controller (PI) show good steady-state response. When an intelligent controller like fuzzy controller is used, the same system exhibits better dynamic response.

II. **Positive Output KY Voltage Boosting Converter**

The power circuit of second order-d KY-VBC is depicting in Fig.1 (a). It consists dc input supply voltage $V_{in}$, four MOSFET power switches $S_{11}$, $S_{12}$, $S_{21}$, and $S_{22}$ along with their corresponding body diodes $D_{11}$, $D_{12}$, $D_{21}$, and $D_{22}$, energy transferring capacitors $C_{E1}$ and $C_{E2}$, output inductor $L$, output capacitor $C_o$, freewheeling diodes $D_1$ and $D_2$, output current $i_o$ and load resistance $R$. The converter is assumed that all the elements are ideal as well as the same converter operates in CCM. Fig.1 (b) and Fig. 1 (c) show the modes of operation of the converter.

During state 1 (refer the Fig. 1(b)), the switches, $S_{12}$ and $S_{21}$ are closed and switches, $S_{11}$ and $S_{22}$ are open, the potential across inductor $L$ is equal to $V_{in}$ (across the $C_{E1}$) plus $2V_{in}$ (across the $C_{E2}$) and then subtract $V_o$ (the output voltage). The current passing through the $C_o$ is equal to $i_L - i_o$. During state 2 (refer the Fig. 1(c)), the switches, $S_{12}$ and $S_{21}$ are open and switches, $S_{11}$ and $S_{22}$ are closed, the potential across the inductor $L$ is equal to $2V_{in}$ (across the $C_{E2}$) and then subtract the $V_o$. The current through the $C_o$ is equal to $i_L - i_o$.

The voltage transfer gain of this converter (by applying the voltage balance to states 1 and 2 operation of the converter) is expressed as follows.

$$G = \frac{V_o}{V_{in}} = 2 + d$$  \hspace{1cm} (1)
TABLE I
Designed POKYVBC

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Symbol</th>
<th>Value</th>
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<tbody>
<tr>
<td>Input Voltage</td>
<td>$V_{in}$</td>
<td>12V</td>
</tr>
<tr>
<td>Output Voltage</td>
<td>$V_o$</td>
<td>28V</td>
</tr>
<tr>
<td>Inductor</td>
<td>$L$</td>
<td>10µH(component change)/20 µH</td>
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<tr>
<td>Capacitors</td>
<td>$C_0, C_{E1}, C_{E2}$</td>
<td>1000 µF, 680 µF, 100 µF</td>
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<tr>
<td>Nominal switching</td>
<td>$I_s$</td>
<td>100kHz</td>
</tr>
<tr>
<td>frequency</td>
<td></td>
<td></td>
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<tr>
<td>Load resistance</td>
<td>$R$</td>
<td>15ohm</td>
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<tr>
<td>Input Power</td>
<td>$P_{in}$</td>
<td>56.28W</td>
</tr>
<tr>
<td>Output Power</td>
<td>$P_o$</td>
<td>50.4W</td>
</tr>
<tr>
<td>Input Current</td>
<td>$I_{in}$</td>
<td>4.69A</td>
</tr>
<tr>
<td>Output Current</td>
<td>$I_o$</td>
<td>1.8A</td>
</tr>
<tr>
<td>Adopted Value of</td>
<td>$D$</td>
<td>0.33</td>
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<tr>
<td>Duty Ratio</td>
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III. SIMULATION STUDY

A detailed simulation study is performed for the designed system in MATLAB R2013a/Simulink platform with ode45 (Dormand-Prince) solver. The performance of the SMC is obtained first then compared with the typical PI controller (PIC). A PI controller with settings $K_p = 0.1205$ and $T_i = 0.00016s$, which are obtained by the Ziegler-Nichols tuning technique is used [12]. The verification of the complete model performance is made for various working states through start-up transient, line variation, load variation, steady state region and in addition circuit elements modifications. The complete schematics developed in Simulink environment respectively for PIC and FLC are shown in Fig.2 and Fig.3. A two input and one output FLC is defined in Fig.4. The membership functions for output voltage error and change in output voltage error are indicated in Fig.5 and Fig.6 respectively. The defined rules of Fig.7 are more illustrated in the rule viewer in Fig.8. The surface view of the designed FLC is shown in Fig.9.
Fig. 6 Membership function for change in error

Fig. 7 Fuzzy rule

Fig. 8 Rule viewer

Fig. 9 Surface view

Fig. 10 Start up transients in PIC and FLC

Fig. 11 Membership function for change in error

Fig. 12 Fuzzy rule

Fig. 13 Rule viewer

Fig. 14 Surface view

Fig. 15 Start up transients in PIC and FLC

Fig. 16 Membership function for change in error

Fig. 17 Fuzzy rule

Fig. 18 Rule viewer

Fig. 19 Surface view

Fig. 20 Start up transients in PIC and FLC

Fig. 21 Membership function for change in error

Fig. 22 Fuzzy rule

Fig. 23 Rule viewer

Fig. 24 Surface view

Fig. 25 Start up transients in PIC and FLC

Fig. 26 Membership function for change in error

Fig. 27 Fuzzy rule

Fig. 28 Rule viewer

Fig. 29 Surface view

Fig. 30 Start up transients in PIC and FLC

Fig. 31 Membership function for change in error

Fig. 32 Fuzzy rule

Fig. 33 Rule viewer

Fig. 34 Surface view

Fig. 35 Start up transients in PIC and FLC

Fig. 36 Membership function for change in error

Fig. 37 Fuzzy rule

Fig. 38 Rule viewer

Fig. 39 Surface view

Fig. 40 Start up transients in PIC and FLC

Fig. 41 Membership function for change in error

Fig. 42 Fuzzy rule

Fig. 43 Rule viewer

Fig. 44 Surface view

Fig. 45 Start up transients in PIC and FLC

Fig. 46 Membership function for change in error

Fig. 47 Fuzzy rule

Fig. 48 Rule viewer

Fig. 49 Surface view

Fig. 50 Start up transients in PIC and FLC

Fig. 51 Membership function for change in error

Fig. 52 Fuzzy rule

Fig. 53 Rule viewer

Fig. 54 Surface view

Fig. 55 Start up transients in PIC and FLC

Fig. 56 Membership function for change in error

Fig. 57 Fuzzy rule

Fig. 58 Rule viewer

Fig. 59 Surface view

Fig. 60 Start up transients in PIC and FLC

Fig. 61 Membership function for change in error

Fig. 62 Fuzzy rule

Fig. 63 Rule viewer

Fig. 64 Surface view

Fig. 65 Start up transients in PIC and FLC

Fig. 66 Membership function for change in error

Fig. 67 Fuzzy rule

Fig. 68 Rule viewer

Fig. 69 Surface view

Fig. 70 Start up transients in PIC and FLC

Fig. 71 Membership function for change in error

Fig. 72 Fuzzy rule

Fig. 73 Rule viewer

Fig. 74 Surface view

Fig. 75 Start up transients in PIC and FLC

Fig. 76 Membership function for change in error

Fig. 77 Fuzzy rule

Fig. 78 Rule viewer

Fig. 79 Surface view

Fig. 80 Start up transients in PIC and FLC
### Table II
**TDS at starting up**

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<th>TDS</th>
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<td>0.24x10^{-3}</td>
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<tr>
<td>Rise Time (s)</td>
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<tr>
<td>Peak Time (s)</td>
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<td>Settling Time(s)</td>
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<tr>
<td>Steady state error</td>
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Fig.11 Response to step change in input - 25V to 28V at 0.05s

### Table III
**TDS at step change in input**

<table>
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<tr>
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<td>Settling Time(s)</td>
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<td>0</td>
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Fig.12 Response to step load change from 15.6Ω to 20 Ω at 0.05s

Fig.13 Enlarged view of response during load step change (15.6Ω to 20 Ω) at 0.05s

Fig.14 Enlarged view of response during load step change (20 Ω to 15.6Ω) at 0.05s
The line regulation is studied in Fig.15 and Fig.16. The Fig.15 elaborates the response of POKYVBC for the step change in input from 8V to 12V at 0.05s. Similarly Fig.16 studies the dynamics of output voltage for input voltage step change from 12V to 8V. The study also considers circuit component changes. A representative case of step change in inductor from 15mH to 20mH at 0.05s is detailed in Fig.17 and later in Fig.18 as enlarged view. The output voltage ripple is studied in Fig.19 as 0.012V.

![Fig.15 Step change in input (line regulation) from 8V to 12V at 0.05s](image1)

![Fig.16 Step change in input (line regulation) from 12V to 8V at 0.05s](image2)

![Fig.17 Response to step change in inductor from 15mH to 20mH at 0.05s](image3)

![Fig.18 Enlarged view of inductor change at 0.05s](image4)

![Fig.19 Output voltage ripple of FLC](image5)

IV. EXPERIMENTAL STUDY

The simulation results are verified in an experimental investigation. A prototype POKYVBC is developed for the specification given in Table 1. MOSFET IRFN 540 is taken as power switch, the D <sub>1</sub> - D <sub>2</sub> are FR306, Capacitors C<sub>0</sub>, C<sub>E1</sub> and C<sub>E2</sub> are respectively with 1000µF, 680µF and 100µF and 100V, Electrolytic and plain polyester type, and the inductor is 20µH (variable)/5A (Ferrite Core). Fig.20 shows the output response to the step increase in the input voltage while Fig.21 presents similar response to the step decrease in input voltage for FLC.
TABLE IV
Designed POKYVBC

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<tr>
<td>Nominal switching</td>
<td>$f_s$</td>
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<tr>
<td>Adopted Value of Duty Ratio</td>
<td>$D$</td>
<td>0.33</td>
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</table>

Fig.20 Experimental setup

Fig.21. Photograph of POKYVBC using FLC

Fig.22 Output voltage regulation during step increase in input voltage

Fig.23 Output voltage regulation during step decrease in input voltage
V. CONCLUSION

In this paper, the design, analysis, simulation study, and experimental verification of PIC and FLC for output voltage regulation in the second order-d KY-VBC operated in CCM have been successfully demonstrated. The simulation results of FLC have shown that excellent load voltage control, good dynamic responses, and reduced output voltage ripple in comparison with linear PIC. Therefore, the system achieves a robust output voltage against load disturbances and input voltage variations to guarantee the output voltage to feed the load without instability. This control approach has several advantages: stability even for large supply, load variations, and circuit components variations, robustness, good dynamic behavior, and simple implementation.

REFERENCE