



Fuzzy Logic Controller Implementation for Buck Converters: A Comparative Study Between Simulink and Arduino-Based Systems

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ABSTRACT

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Keywords:

Fuzzy logic controller ;hardware Buck converter; simulink buck converter ; input voltage, output voltage, duty cycle.

This work presents a comparative study between two buck converters controlled by a fuzzy logic controller (FLC): one developed and simulated in MATLAB/Simulink, and the other hardware using an Arduino board. The objective is to evaluate the performance of the FLC in both simulation and real-time environments by varying the input voltage and observing the response of each system. In both cases, the same fuzzy logic controller structure is used, with inputs representing the output voltage error and its derivative, and an output that determines the appropriate duty cycle. The duty cycle is then applied to control the Mosfet of each buck converter. Multiple input voltage values are applied to both systems, and the corresponding output voltages are measured and analyzed. Results show that the Arduino-based hardware implementation achieves better output voltage regulation, especially when the input voltage is significantly higher than the desired output. This indicates that real-time execution of the FLC in a physical system can offer better dynamic performance. The findings highlight the practical effectiveness of intelligent controllers in embedded systems and provide valuable insights into hardware-versus-simulation behavior under varying tests

1.INTRODUCTION

Among the most important axes in the field of the electrical network, we find the voltage regulation, this expression which is repeated every time when we speak especially of the DC/DC converters, either the converters intended for the MPPT system or the converters intended for the charging of batteries or other uses, for this reason, the field of regulation has become very dynamic in particular in the introduction of the new types and new structures of the correctors. A buck converter using FLC achieves improved voltage regulation and reduced ripple. Implemented using an Atmega microcontroller as a controller, the FLC maintained output stability near the target output voltage under load[1]. A current-controlled switched-capacitor DC-DC converter uses FLC to achieve fast dynamic response, low output ripple, and robustness under load and supply variation (simulated in MATLAB/Simulink)[2]. Concerning a new hybrid Fuzzy-PI controller outperforms standard PI control in simulation, showing better stability and regulation under varying load, input, and reference

voltages[3]. The adaptive fuzzy logic controller is always present to optimize power flow and improve voltage regulation in a hybrid PV/wind microgrid, enhancing stability, MPPT efficiency, and power quality[4]. Simulation-based evaluation showed that FLC exhibits less oscillation and better closed-loop response than Internal Model Control (IMC) on a buck converter model in MATLAB/Simulink[5]. A master's thesis demonstrates a Fuzzy-PID controller regulating output in CCM operation of a switched-inductor buck, improving stability and speed while reducing steady-state error[6]. Implemented on a dSPACE experimental platform, the Neuro-Fuzzy controller adapts to reference and load changes, outperforming a PI controller in dynamic response[7]. A Simulink-based comparison of FLC versus PI for solar-fed DC-DC converters highlights significant advantages in regulation and stability for FLC[8]. A combined fuzzy logic and sliding mode strategy provides robust transient performance and disturbance rejection with reduced chattering in buck converter applications[9]. In this work, we develop a Fuzzy Logic Controller (FLC) to adjust the PWM signal in order to regulate the output voltage and bring it close to the desired setpoint, knowing

that we will use two buck circuits: the first based on Simulink, and the second is a physical circuit regulated via the Arduino Uno. Finally, we compare the results of both techniques

WORKFLOW

II.1 Step1: Design of FLC Inputs and Output

At the beginning we define the inputs and the output of the FLC controller, the latter contains the "Error" input which represents the difference between the measured output voltage and the target output voltage, the second input (Derror) represents the variation of the error, that is to say the difference between the old error and the new error, the output of this controller (Duty) represents the duty cycle which will control the two buck circuits, the following figures represent the inputs and the output of the FLC[10][11][12][13][14][15].

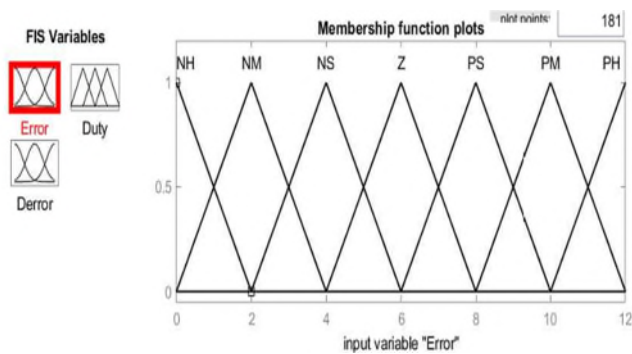


Fig. 1. Error input

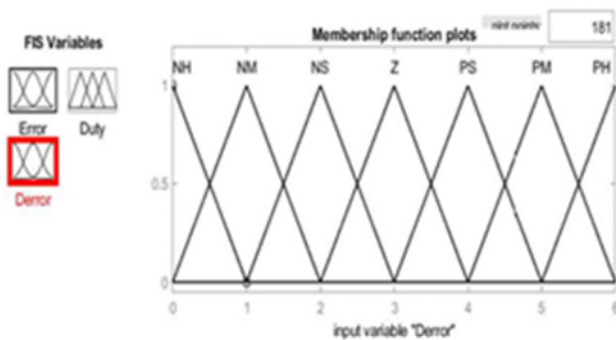


Fig. 2. Derror input.

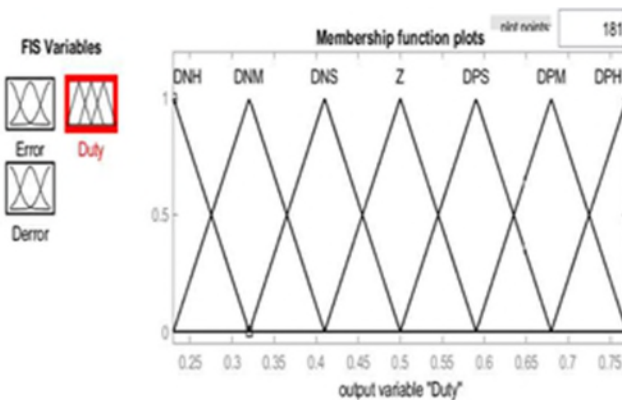


Fig. 3. Duty output.

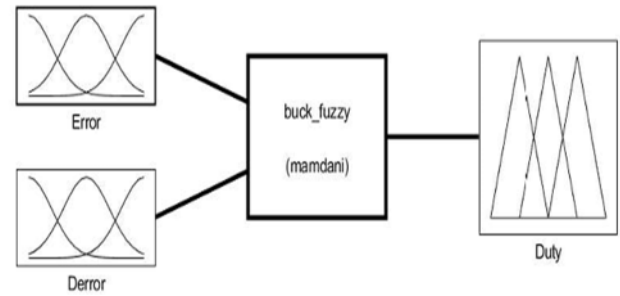


Fig. 4. Structure of the FLC.

II.2 Step2: Definition of FLC Rules

As we notice that each of the inputs and the output contains seven membership functions, so the number of rules is 49, as illustrated in the following table.

TABLE 01. THE RULES

Duty		Error						
		PH	PM	PS	Z	NS	NM	NH
D e r r o r	NH	Z	DNS	DNM	DNH	DNH	DNH	DNH
	NM	DPS	Z	DNS	DNM	DNH	DNH	DNH
	NS	DPM	DPS	Z	DNS	DNM	DNH	DNH
	Z	DPH	DPM	DPS	Z	DNS	DNM	DNH
	PS	DPH	DPH	DPM	DPS	Z	DNS	DNM
	PM	DPH	DPH	DPH	DPM	DPS	Z	DNS
	PH	DPH	DPH	DPH	DPH	DPM	DPS	Z

Where:

PH: Positive High.

PM: Positive Medium.

PS: Positive Small.

Z: Zero.

NH: Negative High.

NM: Negative Medium.

NS: Negative Small.

DNH: Duty Negative High.

DNM: Duty Negative Medium.

DNS: Duty Negative Small.

DPH: Duty Positive High.

DPM: Duty Positive Medium.

DPS: Duty Positive Small.

The 49 rules are summarized in the following graph:

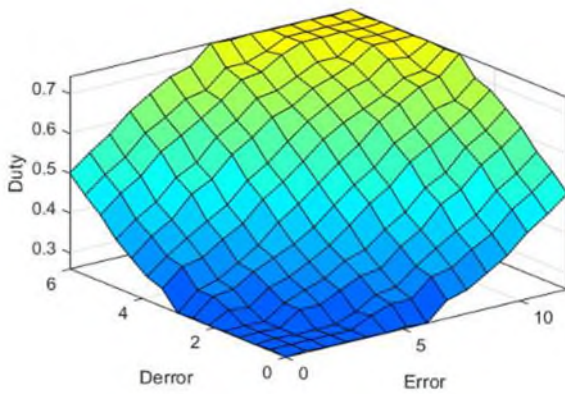


Fig. 5. The 3D surface of the rules.

II.3 Step3: Integration of FLC into the Simulink Circuit

This is the final step before obtaining the results. In this step, the FLC is integrated into the Simulink electrical schematic, [16][17][18][19] which includes a buck converter circuit composed of :

$C = 2000 \mu\text{F}$, $R = 50 \text{ ohms}$, $L = 100 \mu\text{H}$, and switching frequency $f = 10 \text{ kHz}$, as shown in the following figure.

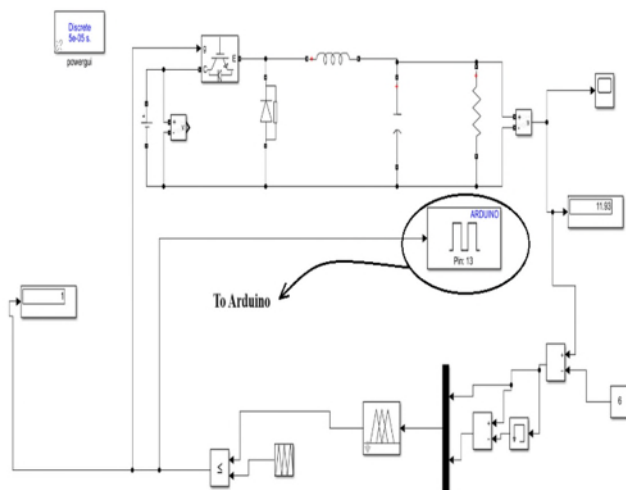


fig.6 . The Simulink circuit.

III. RESULTS

Nb:	Vin	VOD	VOS	VOA
01	18V	6V	16.82 V	12.35 V
02	18V	7V	16.92 V	12.17V
03	18V	8V	16.82 V	11.18 V
04	18V	9V	17.47 V	10.91V
05	18V	10V	17.42 V	10.42 V
06	18V	11V	17.34 V	10.05 V
07	18V	12V	17.34 V	10.38 V
08	18V	13V	17.25 V	09.99 V
09	18V	14V	17.04 V	09.66 V
10	18V	15V	16.93 V	09.46 V
11	15V	06V	13.69 V	08.67 V
12	15V	07V	13.49 V	08.41 V

13	15V	08V	14.41 V	08.14 V
14	15V	09V	14.41 V	08.11 V
15	15V	10V	14.38 V	08.12 V
16	15V	11V	14.11 V	07.74 V
17	15V	12V	14.15 V	08.03 V
18	15V	13V	14.09 V	07.60 V
19	12V	06V	10.90 V	06.56 V
20	12V	07V	11.54 V	06.77 V
21	12V	08V	11.30 V	06.05 V
22	12V	09V	11.33V	06.10 V
23	12V	10V	11.31 V	06.15 V

Where:

Vin: input voltage.

VOD: target output voltage.

VOS: Simulink output voltage.

VOA: Arduino output voltage.

The following figures represent the voltages , VOD, VOS and VOA for the input voltages $V_{in}=18\text{V}$, $V_{in}=15\text{V}$ and $V_{in}=12\text{V}$. as well as the difference between the VOD voltage and the VOA voltage represented by $\Delta V1$, and the difference between VOD and VOS represented by $\Delta V2$

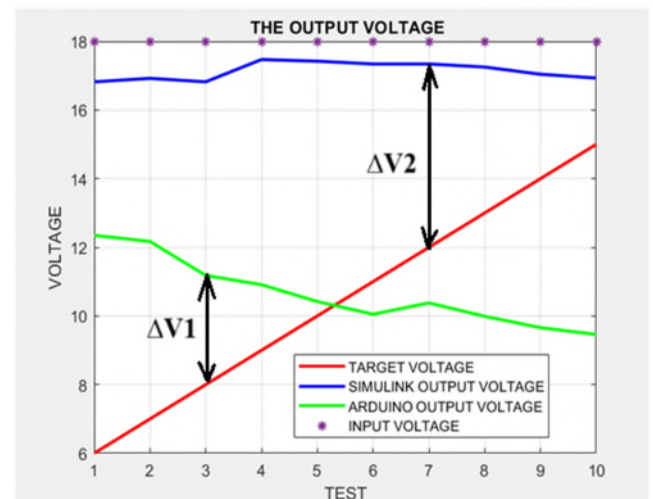


Fig . 7. VOD,VOS,VOA graph with $V_{in}=18\text{V}$.

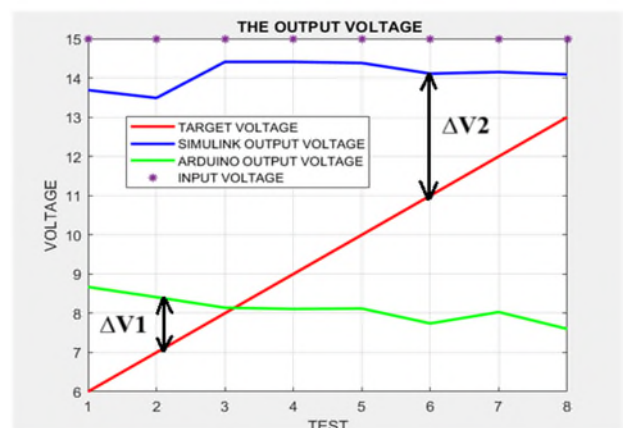


Fig . 8. VOD,VOS,VOA graph with $V_{in}=15\text{V}$

Electronic circuit

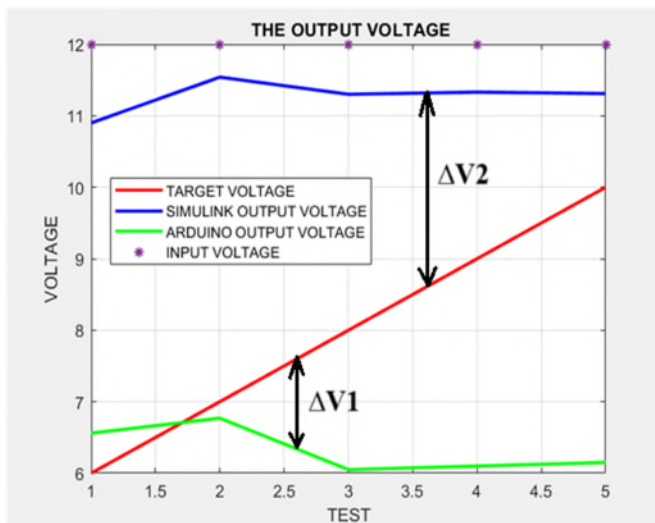


Fig. 9. VOD,VOS,VOA graph with $V_{in}=12V$

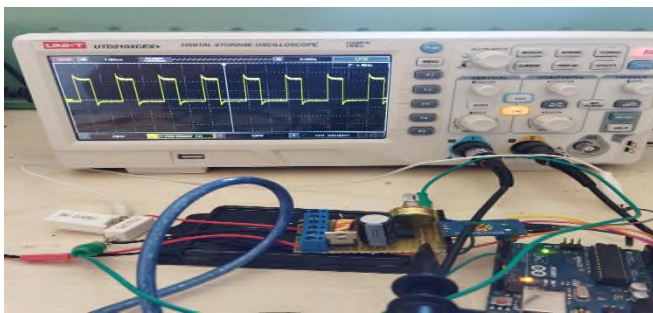
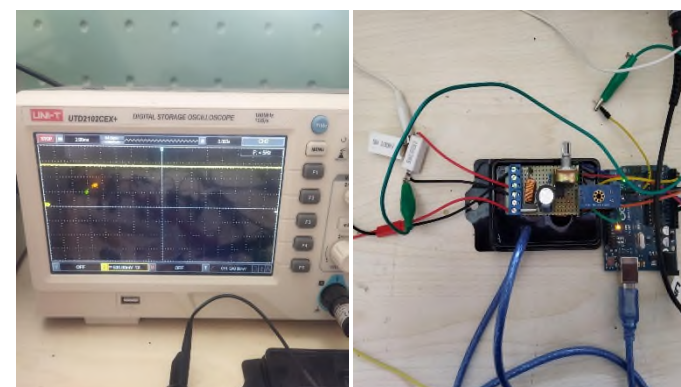


Fig. 10. Electronic circuit

V. COMMENTS



1. Firstly, it can be said that ΔV_1 is always lower than ΔV_2 , which indicates that the Arduino-based buck converter is more accurate compared to the one in Simulink.
2. It can also be said that we successfully managed to control the Arduino-based buck converter using the FLC output generated by the Simulink circuit.

3. Despite unfavorable conditions, including changes in the setpoint and input voltage, the Arduino-based buck converter was able to follow the setpoint.

V. CONCLUSION

In this work, we developed and tested two DC-DC buck converter circuits. The first circuit was controlled by a Fuzzy Logic Controller (FLC) implemented in MATLAB/Simulink. The second circuit was a physical buck converter, also regulated using the same FLC, but integrated through an Arduino Uno for real-time control. After thorough testing, the hardware-based buck converter produced better and more accurate results compared to the simulated version.

The main objective of this study was to compare the performance of the FLC in both simulation and experimental setups. The outcomes clearly demonstrated that the results obtained from simulation are not always perfectly aligned with those measured in practical experiments. This discrepancy emphasizes the importance of validating control strategies not only through simulations but also on real hardware to ensure their effectiveness under real-world conditions.

This work successfully achieved its goals and offers a foundation for further improvements. In future research, more advanced control techniques such as adaptive fuzzy control, machine learning-based optimization, or hybrid intelligent systems could be explored. Additionally, the hardware circuit can be optimized in terms of design and efficiency to achieve even better performance in terms of voltage regulation, response time, and robustness.

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