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Fuzzy Logic Control of Fast Transient Response DC-DC Converter

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Abstract: In this paper, a fast transient buck converter using soft computing method is introduced. The regional anatomy of the FRDB is composed of two buck converters connected in parallel, each one of them with different characteristics. FRDB provides a faster transient response to match the challenges of the power supply requirements for fast dynamic input and load changes. It also offers better stability and works out the compensation problem of the error amplifier in duty ratio control. The Control algorithm is developed in this work to ensure tracking of the reference voltage and rejection of system disturbances by successive measurements of the converter output voltage at certain time instants within a conduction period. The main objective is simulation of Fuzzy logic controls using MATLAB software to evaluate the controller's performances. The simulation results shows Fuzzy controller performs effectively for the chosen converter.

Key words: DC-DC Converter · Fast Response Double Boost · Fuzzy Logic Controller

INTRODUCTION

DC-DC converters play a substantial role in the industry, the aerospace industry, portable systems, distributed generation, electrical devices, electrical cars, power factor correction and voltage regulation [1-5]. Therefore, high-quality power supplying converters that can accomplish low-cost and high-efficiency performance are in demand [6]. Buck converters, as unitary of the widely used converters, have been investigated with different social systems and control methods [7-18]. These types of devices need power supplies with the low output voltage, high output current and the main challenge of fast transient response [19-22]. Different techniques used in order to improve the transient response of these types of power supplies: The fast response double buck converter (FRDB converter) was presented like a dc–dc switching converter, which can be considered an alternative to the voltage regulator module (VRM) converters in some applications [23]. PI controller is applied in this work for determining the output potential of fast response double bock (FRDB) converter under supply and load disturbances. Tests for load regulation and line regulation are held away to evaluate the controllers' performances. The results are presented and evaluated.

Fast Response Double Buck Converter (FRDB): The regional anatomy of this converter is composed of two switching converters connected in parallel. It is critical to take into account the fact that although both converters are connected in parallel, they sustain to be designed with different roles and therefore, the surgical procedure does not match a typical parallel operation. In the FRDB converter, the main switching converter must be designed to work in the steady-state operation and therefore with good stability and a low output voltage ripple, but consequently with slow reaction. On the reverse, the auxiliary switching converter must be designed to run in transient operation. The primary purpose of the auxiliary converter is to provide the required high current slew rate and quick transient response. Nevertheless, low output voltage ripple is not a prerequisite for the auxiliary converter. Fig. 1 shows the block diagram of the FRDB converter. The circuit diagram of the FRDB converter shown in Fig. 2. In this design, two buck topologies have been used to design the auxiliary and main converter. Both of them feed the output in parallel. Furthermore, a control block can be detected. Essentially, the control block is composed of direct control, non-linear control and ultimately, a multiplexer (MUX). In short and from a topological point of view, the principle operation is based on preventing the main

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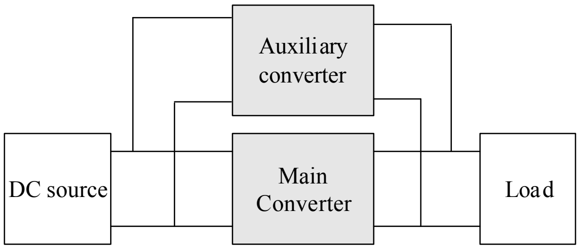


Fig. 1: Structure of fast response double buck converter

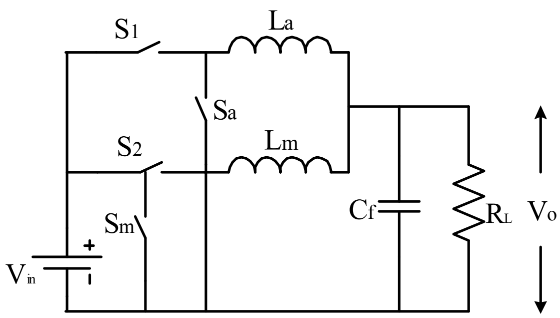


Fig. 2: Circuit diagram of fast response double buck converter

switching converter operating all the time, connecting the auxiliary switching converter only at the edges of the load current steps. In this manner, the auxiliary converter completes the main converter performances to satisfy the demands.

The output voltage equation of FRDB given by,

$$V_L = \frac{di_L}{dt} \tag{1}$$

During ON time, the current is

$$\Delta iL_{off} = \int_0^{t_{on}} \frac{V_L}{L} dt$$

$$= \frac{V_i - V_O}{L} t_{on}, t_{on} = DT \tag{2}$$

Current during OFF state is given by,

$$\Delta iL_{off} = \int_0^{t_{on}+t_{off}} \frac{V_L}{L} dt$$

$$= \frac{-V_O}{L} t_{off}, t_{off} = (1-D)T \tag{3}$$

$$\frac{(V_i - V_O)}{L} t_{on} - \frac{V_O}{L} t_{off} = 0 \tag{4}$$

$$(V_i - V_O)DT - V_O(1-D)T = 0 \tag{5}$$

$$V_O - DV_i = 0 \tag{6}$$

$$D = \frac{V_O}{V_i} \tag{7}$$

Control of FRDB: The main switching converter must be designed to work in steady and a low output voltage ripple, but consequently with slow response. On the contrary, the auxiliary switching converter must be designed to work in transient operation. The main aim of this converter is to provide the required high current slew rate and fast transient response [24]. The auxiliary converter acts as simple switch. The inductor connected with the auxiliary converter gets charged and discharged based on the condition of output voltage level. Inductor gets charged, when the output voltage exceeds beyond the upper threshold limit. i.e. the extra current is used for charging the inductor, thus the auxiliary converter helps to take out the extra current. Inductor gets discharged, when the output voltage level goes below the lower threshold limit. i.e. the additional current required is supplied by the inductor when it discharges. Thus the voltage level is maintained within the threshold limit by the auxiliary converter action. The duty cycle saturation & reset logic block forces to “1" the duty cycle if lower threshold is surpassed, or it set the duty cycle to “0” if output voltage is above the high threshold. In short and from a topological point of view, the principle operation is based on keeping the main switch converter operating all time; connect the auxiliary switching converter only at the edges of the load current steps. In this way, the auxiliary converter completes the main converter performance in order to fulfill the requirements.

Fuzzy Logic Controller: Fuzzy logic is a part of artificial intelligence or machine learning which interprets a human’s actions. Computers can interpret only true or false values, but a human being can reason the degree of truth or degree of falseness. Fuzzy models interpret the human actions and are also called intelligent systems. Fuzzy logic is not logic that is fuzzy, but the logic that is used to describe fuzziness. Fuzzy logic is the theory of fuzzy sets, sets that calibrate vagueness. It is based on the idea that all things admit of degrees. In other words, fuzzy logic is a set of mathematical principles for knowledge representation based on degrees of membership. Fuzzy logic reflects how people think. It attempts to model our sense of words, our decision making and our common sense. As a result, it is leading to new, more human, intelligent systems. Fuzzy control provides a formal methodology for representing, manipulating and implementing a human's heuristic knowledge about how to control a system.

The fuzzy controller has the following main components

- The "rule-base" holds the knowledge, in the form of a set of rules, of how best to control the system.
- The inference mechanism evaluates which control rules are relevant at the current time and then decides what the input to the plant should be.
- The fuzzification interface simply modifies the inputs so that they can be interpreted and compared to the rules in the rule-base.
- The defuzzification interface converts the conclusions reached by the inference mechanism into the inputs to the plant.

For the design of fuzzy logic controller the following design steps are to be followed:

- Choice of state and control variables
- Select inference method.
- Fuzzification. Process of making a crisp quantity fuzzy
- Design the knowledge base.
- Select defuzzification method.
- Test and tuning.
- Produce a Lookup table.

The derivation of fuzzy control rules is based on the following criteria:

- When the output of the converter is far from the set point, the change of duty cycle must be large so as to bring the output to the set point quickly.
- When the output of the converter is approaching the set point, a small change of duty cycle is necessary.
- When the output of the converter is near the set point and is approaching it rapidly, the duty cycle must be kept constant so as to prevent overshoot.
- When the set point is reached and the output is still changing, the duty cycle must be changed a little bit to prevent the output from moving away.
- When the set point is reached and the output is steady, the duty cycle remains unchanged.
- When the output is above the set point, the sign of change of duty cycle must be negative and vice versa.

Fuzzy memberships NL, NM, NS, ZE, PS, PM, PL are defined as negative large, negative medium, negative small, zero, positive small, positive medium and positive large.

Fuzzy Logic Toolbox available in MATLAB used in this research work for implementation of the Fuzzy controller. It allows several things to be done, but the most important things are to be a place where a fuzzy inference system can be created or edited. Figs. 4, 5 and 6 show the Fuzzy Proportional and Integral gain response over error and change in error and fuzzy rule for proposed FRDB respectively.

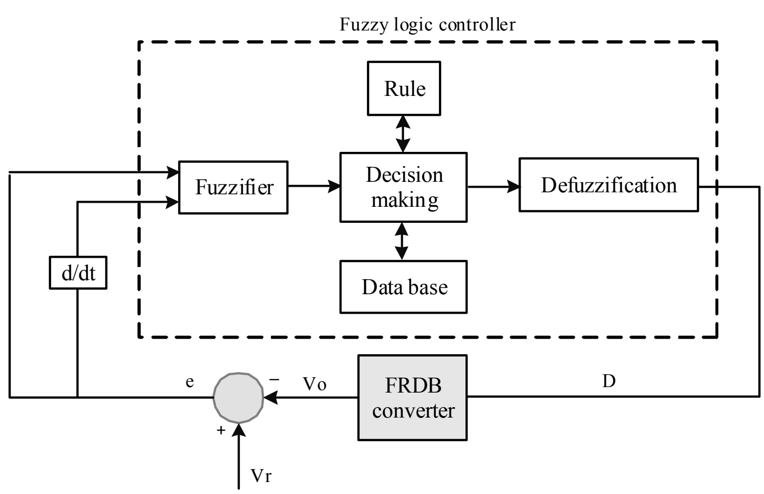


Fig. 3: Block diagram of fuzzy logic controller

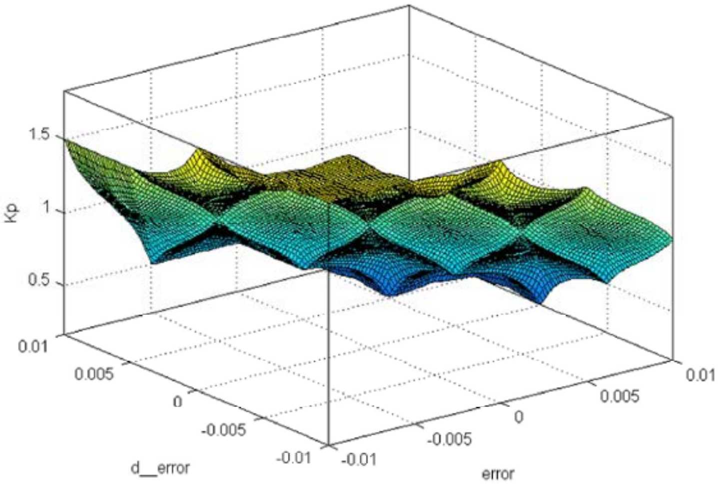


Fig. 4: Fuzzy Proportionality gain response over error and change in error

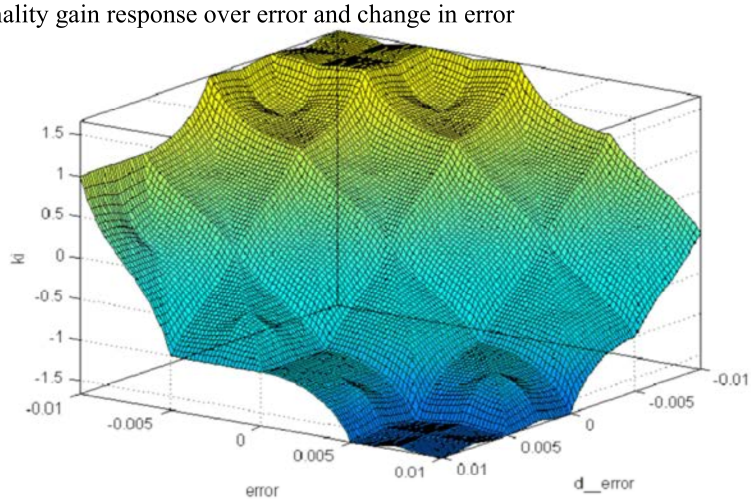


Fig. 5: Fuzzy Integral gain response over error and change in error

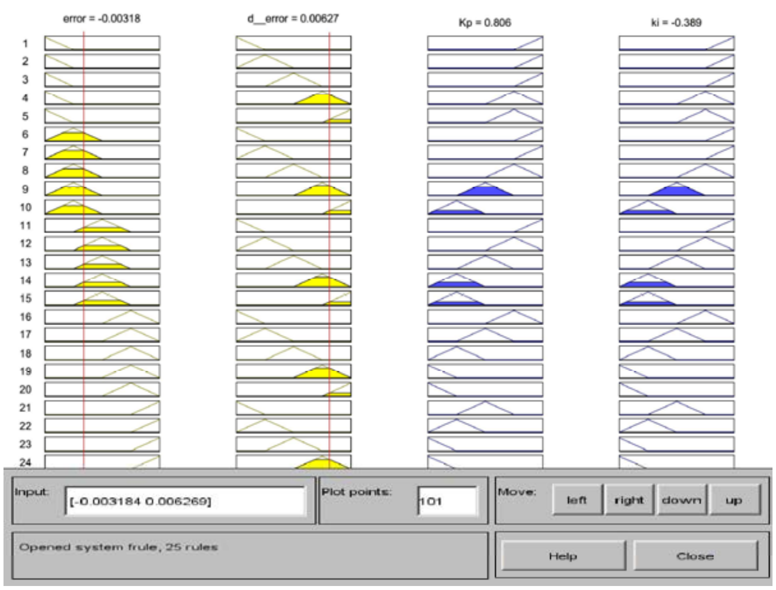
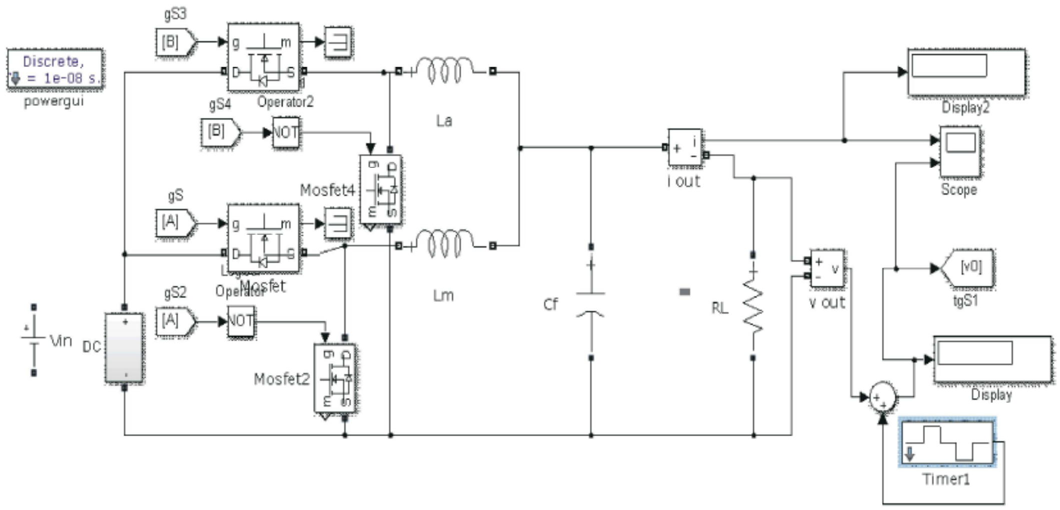


Fig. 6: Fuzzy rule base response over error, change in error and gains

(a)



(b)

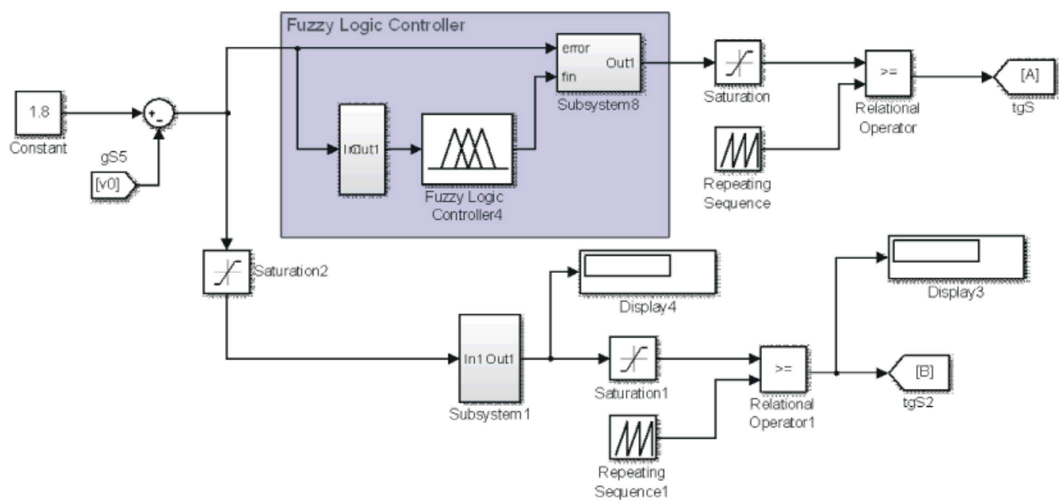


Fig. 7: (a) Overall Simulink of FRDB converter using fuzzy logic control (b) Fuzzy logic controller duty control

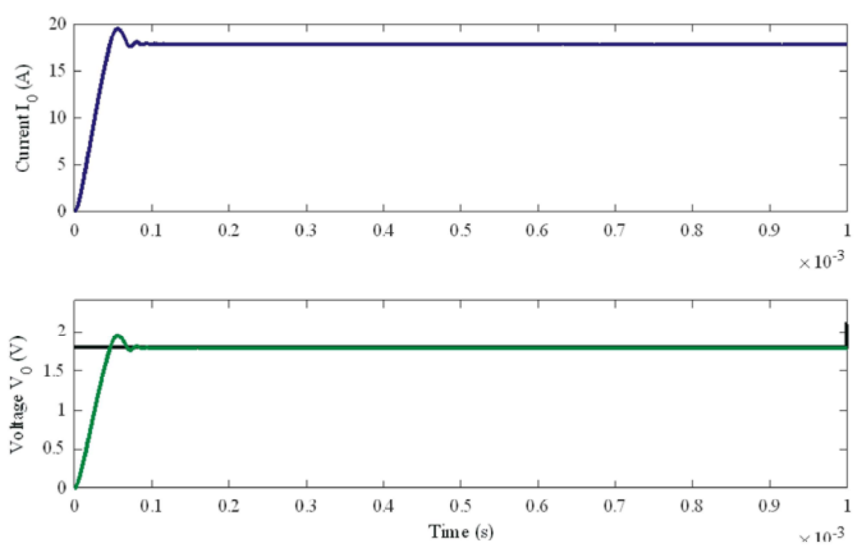


Fig. 8: Simulated start-up of the output voltage and current with set point 1.8V and nominal load 100Ω

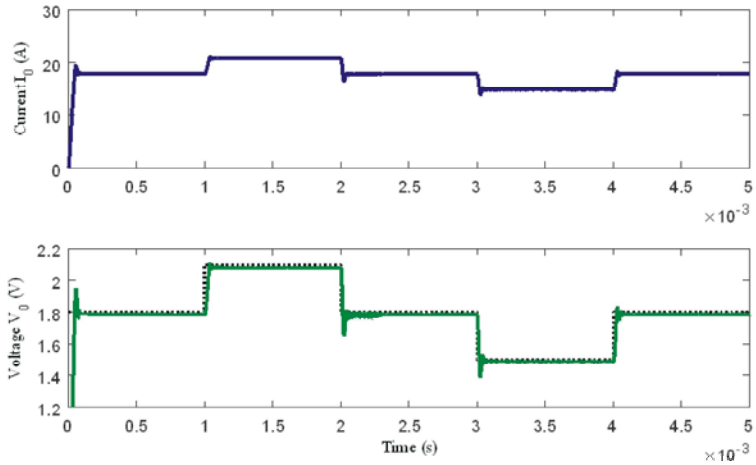


Fig. 9: Simulated output voltage with line disturbances (1.8V-2.1V-1.8V) under nominal load 100 Ω

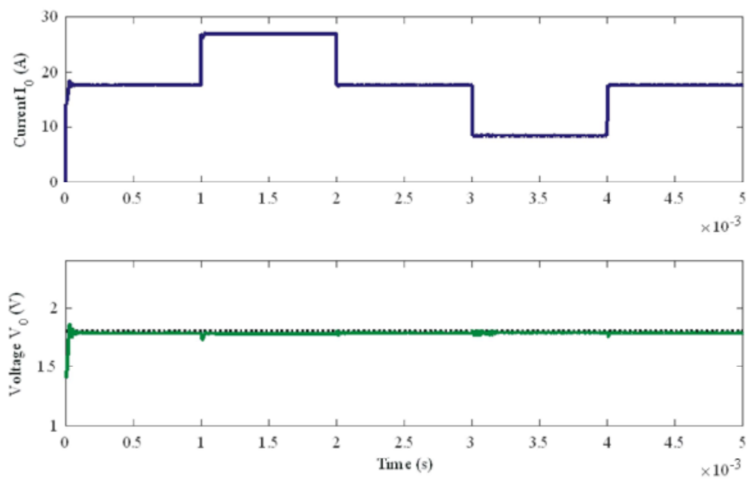


Fig. 10: Simulated output voltage with load disturbances (18A –28A -18A)

Table I: Performance indices of FRDB converter

	Start-up		Sudden line disturbance		Sudden load disturbances	
Converter	T_s (msec)	$\%M_p$	T_s (msec)	$\%M_p$	T_s (msec)	$\%M_p$
FRDB	0.0834	0.83	0.0011	-	0.0049	-

Simulation Results: The proposed Fast Response Double Buck (FRDB) converter control strategies are checked by the controlling duty ratio using fuzzy logic controller fuzzy controller under supply and load disturbances. The Simulink diagram of the proposed FRDB converter shown in Fig.7. Figs. 5-6 show the closed loop response of start-up of output voltage and current of the positive output switched capacitor Luo converter with set point 24V and nominal load 100 Ω. The simulated graphical analysis of the both converter shown Fig. 8 to 13. Fig.5 shows the open loop analysis of conventional buck converter, from this figure, the response of all curves under various load conditions are not stable, whereas the open loop performance of the proposed FRDB converter is stable shown in Fig.7.

Fig. 8 show the closed loop response of start-up of output voltage and current of the FRDB converter with set point 1.8V and nominal load 100 Ω with fuzzy controller. Fig. 9 display the simulated output voltage and current of the FRDB converter with Fuzzy controller under 33% line disturbances at t=1 msec and 3 msec respectively. Fig. 10 illustrates the simulated output voltage and current of FRDB converter with Fuzzy controller under 50% load disturbances. Table.1 show the performance indices of start-up transient, line and load disturbances respectively with Fuzzy controller.

CONCLUSION

Fast response double Buck converters (FRDB) are composed of two buck converters connected in parallel and controlled by fuzzy logic control. The Simulation results show that the proposed fuzzy logic controller regulates satisfactorily the output voltage of proposed FRDB converter for line and load disturbances. FRDB converter presents an excellent stability, due to fuzzy control, keeping a low output voltage ripple and fast transient response. As well, it allows for reducing the steady-state switching frequency affecting the EMI and the switching losses. This type of devices need power supplies with low output voltage and, as main challenge, fast transient response. From the performance evaluation fuzzy controller has better performance for line and load disturbances. These results validate the effectiveness of the developed fuzzy control and establish the superiority of the proposed fuzzy controller.

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