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TRANSCRIBING THE FUZZY LOGIC TECHNIQUE FOR BUCK-BOOST DC-DC CONVERTER

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Abstract

The present work describes one of the control concepts that can overcome the nonlinearity of the buck-boost converter, improves the settling response by using a Fuzzy Logic Controller (FLC) in regulating the output voltage of the Buck-Boost converter and compare the results with a traditional Buck-Boost controller. The objective of this approach is to design and verify a fuzzy logic that controls a buck-boost converter working in continuous conduction mode. The evaluation of the output voltage in both types is compared to enhance the system performance that ensures a fast-dynamic response and provides stable output voltage. The proposed control concept is verified by digital simulation.

Keywords: Buck-boost converter, Continuous conduction mode, Fuzzy logic controller, Traditional converter.

1. Introduction

Nowadays, many researchers or designers are looking for a widely used, economical and effective controller that meets the requests of the consumer. From the dc-dc converters, we expect a stable output voltage that can be produced during many conditions such as parameter variations and load disturbances. The following research considers the BB converter, which exhibits nonlinear characteristics that are the consequence of the switching process, nonlinear components (inductor, capacitor), etc., in other words, the conventional control techniques such as PID controllers are less effective [1, 2]. The buck-boost dc-dc converter is a device that ensures an output voltage less than, greater than, or equal to the input voltage [3, 4]. The FLC can improve the robustness of the dc-dc converter, this technique enables the required dynamical performance of the signal (large, and small) at the same time, this demand cannot be reached with the linear control technique [5-7].

The FLC depends upon the human knowledge of system behaviour to construct a group of rules i.e. the control process is based on some linguistic rules that decrease the nonlinearity of the model with no need for accurate mathematical modelling of the plant and computational complexity [8]. Fuzzy controllers are designed to adapt the operating points from where they are varied. Figure 1 illustrates the main block diagram of the FLC.

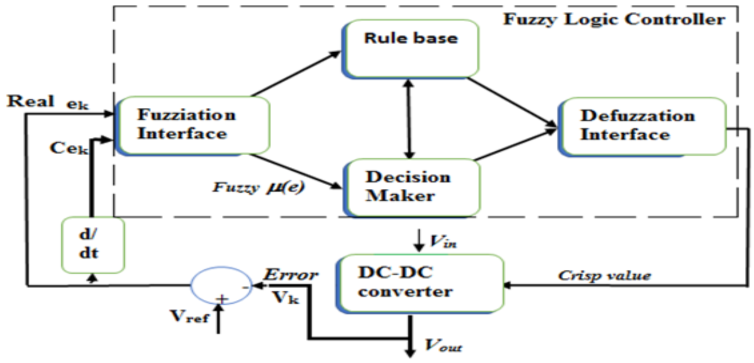

Fig. 1. Main block diagram of the FLC for BB converter.

The major steps in constructing FLC are falsification interface that converts the given data to adequate linguistic expressions; a rule base which estimates the actions with the important linguistic definitions and the control rule set; connection between the human decision procedure and the fuzzy action is done in the decision maker with respect to the knowledge of the control rules and linguistic variable definitions; defuzzification interface which converts non-fuzzy control action from an inferred fuzzy control action. In this work, a fuzzy logic control technique is considered to improve the dynamic characteristics of the Buck-Boost converter to stabilize the output voltage of the converter regardless of variations in input voltage and parameters of the converter. This converter is suitable for application in Photovoltaic Systems, battery-powered systems, and others.

2. Mathematical Model of the BB Converter

The behaviour of any plant can be expressed using the mathematical equations so-called model of the system, these equations depend on the state of the switch

SW. Using Fig. 2. We can find the adequate equation that describes the switching process for BB converter: The state-space equation for the model is show in Eq. (1) and Eq. (2).

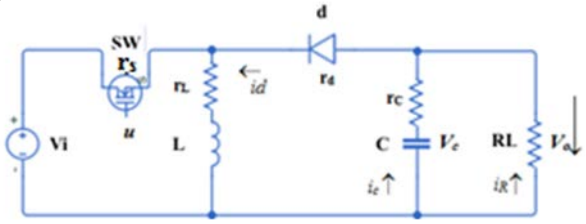

Fig. 2. Real BB converter.

$$\dot{x}(t) = Ax(t) + BV_i(t), V_o(t) = Cx(t) \tag{1}$$

$$A = \begin{bmatrix} -\frac{1}{C(R_L + r_c)} & \frac{R_L(1-D)}{C(R_L + r_c)} \\ -\frac{R_L(1-D)}{L(R_L + r_c)} & \frac{(1-D)(r_c \| R_L - r_d) - r_L - Dr_s}{L} \end{bmatrix},$$

$$B = \begin{bmatrix} 0 \\ \frac{D}{L} \end{bmatrix}, \ C = \begin{bmatrix} \frac{R_L}{(R_L + r_c)} & (1-D) r_c \| R_L \end{bmatrix} \tag{2}$$

The transfer function for the real BB converter working in a CMM is derived from the previous system by using Laplace transform [9, 10]:

$$G(s) = \frac{V_o(s)}{V_i(s)} = \frac{D(1-D)}{LC(1+\alpha_c)} \cdot \frac{C\alpha_c . s + 1}{s^2 + \frac{1}{(1+\alpha_c)}\left(\frac{1}{R_L C} - \frac{R_L \beta}{L}\right)s +} \cdot \frac{1}{+LC(1+\alpha_c)^2((1-D)^2 - \beta)} \tag{3}$$

$$\alpha_c = \frac{r_c}{R_L}, \alpha_d = \frac{r_d}{R_L}, \alpha_s = \frac{r_s}{R_L}$$

$$\beta = (1-D)(\alpha_c - \alpha_d) - (\alpha_L + D\alpha_p)(1 + \alpha_c) \tag{4}$$

where V_i - input voltage, V_o - output voltage, D - duty cycle, C - capacitor, r_s- switch resistance, r_d - diode resistance, r_c - capacitance resistance, R_L - load resistance.

Due to the ON state of the switch SW, the inductor L is directly connected to the input *Vi* resulting accumulation of energy in L, so the output voltage is supplied through capacitor C to the load R_L, as the diode *d* is inversely polarized. During the OFF state of the switch, inductor L is connected directly to C through the diode *d*, enabling the energy to be transferred from L to C and R_L.

The converter output voltage has a polarity opposite to the input voltage and can vary continuously from 0 (theoretically in the ideal case) to -*Vi*. There are three operational modes: (i) buck mode with the output voltage, (ii) boost mode with output voltage above -*Vi*, and (iii) inverter mode with output voltage equal to -*Vi*.

The switching process in the converter circuit is governed by the control circuit, which generates a train of pulses which can be driven to the switch SW, forming the ON, OFF state. The duty cycle ratio D defines the converter operation mode according to:

$$\frac{V_o}{V_i} = -\frac{D}{1-D} \tag{5}$$

where: $\boldsymbol{D} \in (\mathbf{0}, \mathbf{1})$, so the variation of the duty cycle *D*, results in the variation of the output voltage *Vo*, between lower or higher than the input voltage *Vi* in magnitude. When the duty cycle (*D*) is exactly 0.5, *Vo* is equal to -*V*i.

3. Fuzzy Logic Controller Design

The implementation of a fuzzy logic technique is based upon four main stages [11, 12]

3.1. Fuzzification

In this part we convert the input data into linguistic values, the first step is to construct the membership function at the inputs, in our case five fuzzy levels are chosen for the error *e* and the same for change in error *Ce*, these linguistic values are: *NV*-negative big, *NM*-negative small, *NU*-null, *PM*-positive small, and *PV*-positive big. Figure 3 illustrates the FLC in general.

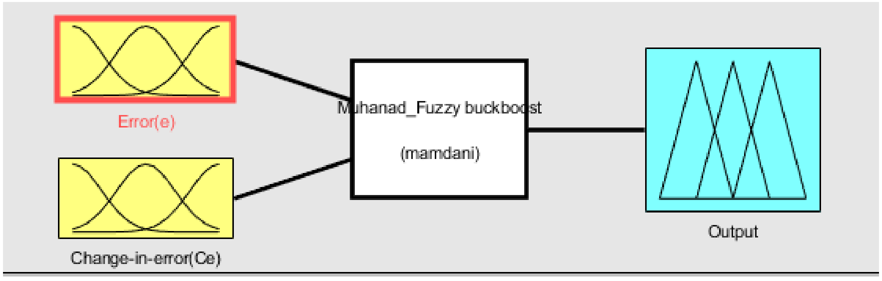

Fig. 3. Fuzzy logic controller in general.

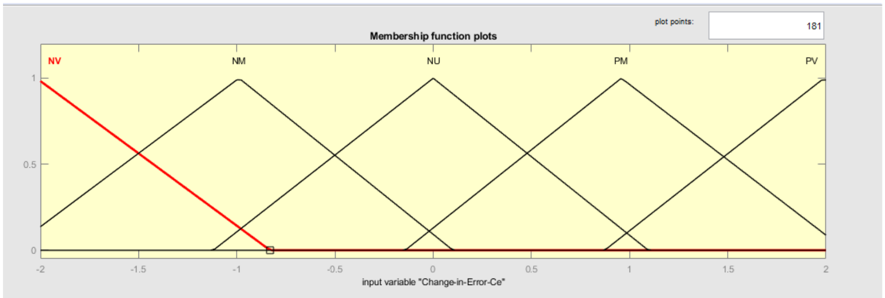

Fig. 3(a). Membership function of the error.

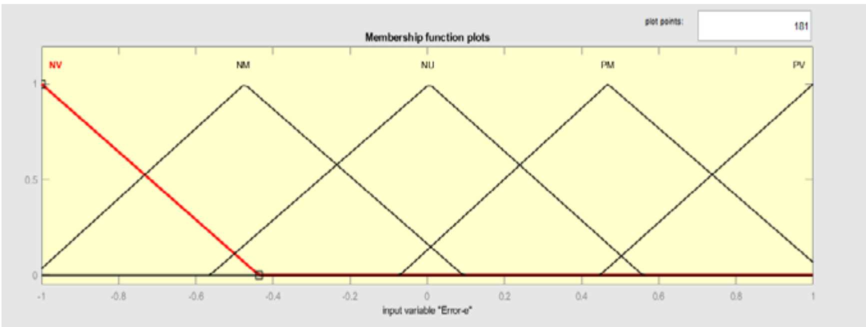

Fig. 2(b). Membership function of the change of error.

3.2. Rule base or decision maker

Knowing the system behaviour enables us to estimate the fuzzy control rules which can be expressed for example If *e* is negative big (NV), and *Ce* is positive small (PM) then output is zero (NU). These rules base is given in Table 2. For the BB converter using FLC. In special cases the rules can be estimated by implementing the "trial and error" process.

Table 2 The rule base.

		Change in error (C_e)				
		NV	**NM**	**NU**	**PM**	**PV**
Error (*e*)	**NV**	NV	NV	NV	NM	NU
	NM	NV	NV	NM	NU	PM
	NU	NV	NM	NU	PM	PV
	PM	NM	NU	PM	PV	PV
	PV	NU	PM	PV	PV	PV

3.3. Inference mechanism

In this part, two demands are important weight factor W_i , and duty cycle C_i, the Mamdani's min fuzzy that contains $\mu e(e(k))$ $\mu Ce(Ce(k))$ produce the weight factor W_i, where $W_i = \min\{\mu e(e(k)), \mu Ce(Ce(k))\}$ and $\mu e(e(k))$, $\mu Ce(Ce(k))$, represent the membership degrees. The duty cycle variation which is deduced by the i-th rule ($Z_i = W_i \text{ x } C_i$) can be expressed as:

$$Z_i = min\{\mu e(e(k)), \mu Ce(Ce(k))\}\, x\, C_i \tag{6}$$

3.4. Defuzzification

In this part, we convert the fuzzy outputs to crisp outputs, where a logical sum of the inference results from each of the rules is obtained (the fuzzy representation of the duty-cycle variation). Using the method of centre of gravity, we can calculate the tenuous value as following:

$$\delta d(K) = \frac{\sum_{i=1}^{4} W_i\, x\, m_i}{\sum_{i=1}^{4} W_i} \tag{7}$$

where m_i- represent the centroid, the contribution of inference result equals the product of centroid and weighting factor and represent the tenuous value of the duty cycle variation. Inputs of the fuzzy controller of the BB converter are the error in output voltage, and the difference in error $Ce = e(i) - e(i-1)$.

4. Simulation Model

For the MATLAB simulation of Buck-Boost converter two models are considered, the first one is the traditional model (see Fig. 4) and the second one is the Buck-Boost converter using fuzzy logic controller Fig. 5. the values of the parameters of the converter are listed in Table 1.

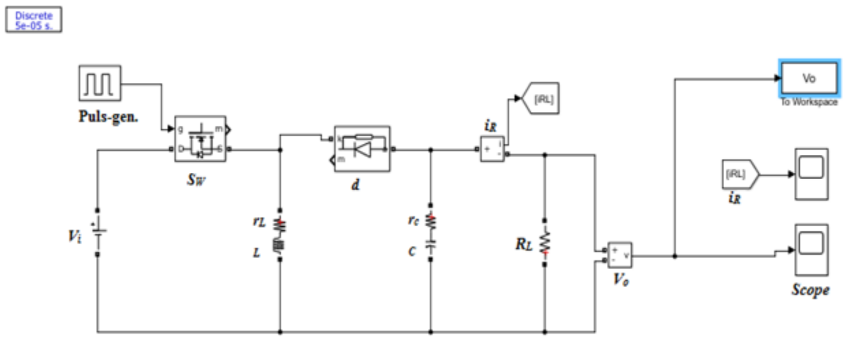

Fig. 4. Traditional BB converter model.

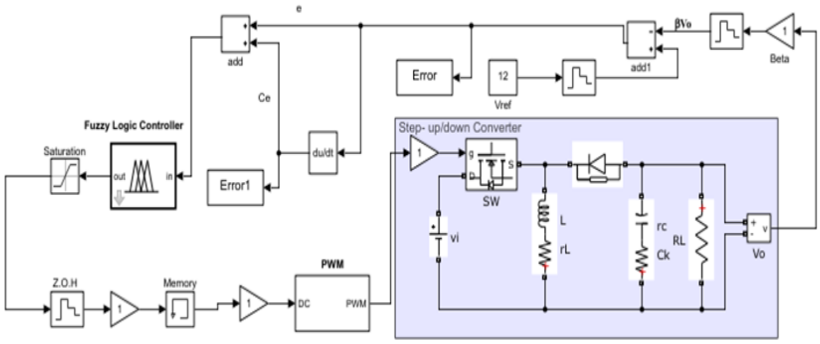

Fig. 5. Simulink model of the BB converter using FLC.

Table 1. BB Converter parameter's value

Description	Parameter	Nominal Value
Input voltage	V_i	12 V
Output voltage	V_o	12 V
Capacitance	C	1470 μF
Inductance	L	300 μH
Load resistance	R_L	34 Ω
Switching frequency	fs	100 kHz
Duty cycle	D	0.5

5. Results and Discussion of the Simulation Model

In this paper, the scenario is to change the duty cycle D according to Eq. (6), to ensure a stable output voltage using the properties of the proposed converter. Fulfilling this demand is reached by considering conventional BB converter, BB converter with PID controller [13] and BB converter with FLC. In Fig. 6. the output voltage is -10.44V, overshoot is 67%, settling time is 40 ms, in Fig. 7. the output voltage is -12V, approximately zero overshoot, and 30 ms with ripple around 0.4V, while in Fig. 8. The output voltage is -12V, with no overshoot, and 20 ms settling time.

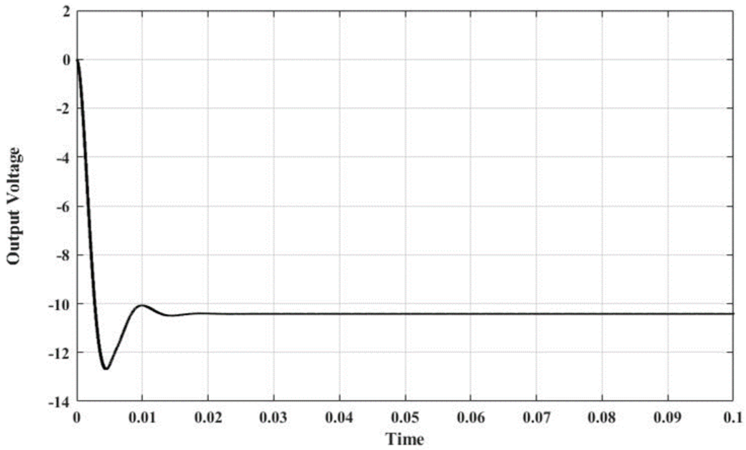

Fig. 6. Output voltage of the BB converter without FLC.

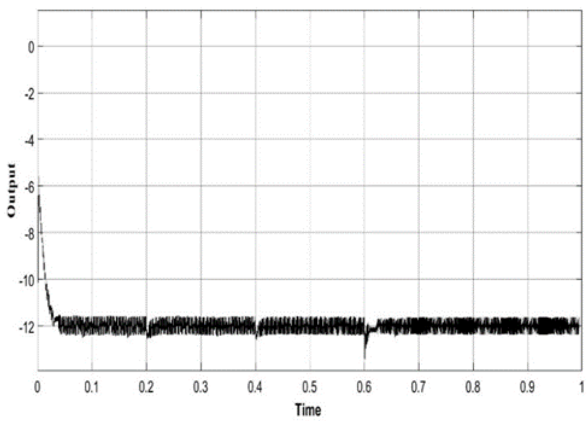

Fig. 7. Output voltage of the BB converter with PID controller.

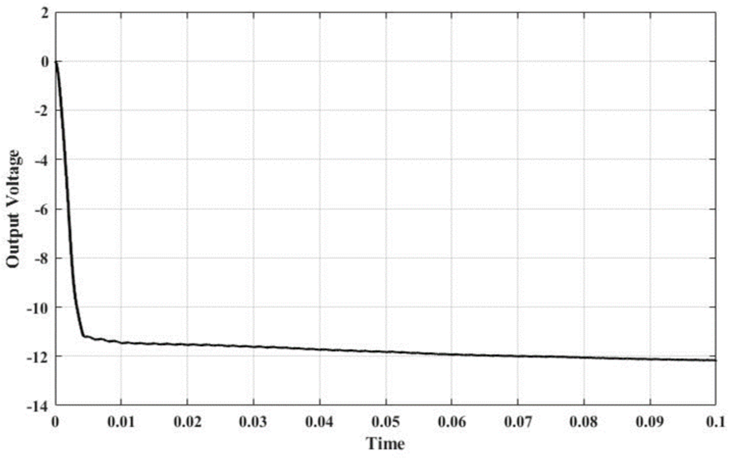

Fig. 8. Output voltage of the BB converter using FLC.

6. Conclusions

The proposed technique of using FLC in regulating the dc voltage of the BB converter operating in CCM is considered in this paper. It ensures high robustness, faster transient response, low output ripple, and better response of the BB converter. The converter performances are verified by means of digital simulation using MATLAB/Simulink. The Simulation procedure leads us to a very effective controller that ensures a better performance due to the controlling procedure without the need for the system model. As a conclusion the fuzzy controller can be an alternative to traditional control technique that ensures considerable control performances as tracking the desired output voltage.

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