# Parameter Optimization of a Fuzzy Logic Controller for a Power Electronics Boost Converter using Genetic Algorithms

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*Abstract:* - A fuzzy logic controller (FLC) for a Boost power electronics converter has been designed. The controller parameters have been optimized using genetic algorithms. Controller design and simulations in Matlab SimPowerSystems are carried out in this paper. The designed fuzzy controller proved significantly better performance compared to two reference controllers; a classical PI controller and a PI controller tuned with FL. The novel topology is based on a literature study fuzzy controllers for this type of converter. Certain modifications have been made in the controller structure with respect to what have been found in the literature, and it is shown that genetic algorithms can be used for deciding optimal controller parameters. The disadvantages of the FLCs were also pointed out. One is that oscillations occur in the controller loop. To find the reason for these oscillations the system must be further investigated. Another disadvantage is the lack of transfer function theory for FLCs. Simulations can be carried out to check the controllers' sensibility towards parametric variations. However, the stability cannot be proven mathematically. Nevertheless, the Boost converter has better performance equipped with a FLC compared to a converter with a PI controller. Based on these experiences FLCs should be used for systems demanding a high accuracy and that follow a repeated reference like a robot arm or a charge/discharge curve of a super-capacitor bank.

*Key-Words:* - Fuzzy Logic Controller – Genetic Algorithms – Boost Converter – Power Electronics

## 1 Introduction

Artificial intelligence (AI) has proven to have a lot of useful applications within the field of electrical engineering and has been used within areas such as forecasting, estimation, modeling and optimization [1][2][8]. AI techniques are non-linear and experience show that they go well together with non-linear systems. Power electronics converters with PI controllers often use look up tables to deal with the non-linearities. Fuzzy logic controllers (FLCs) can have a more stable performance independent of the operating point. Two FLCs for a Boost converter will be designed using genetic algorithms, a powerful optimization tool that can be combined with simulations to find the most suitable solution. A standard PI controller is designed for comparison. In this paper the focus will be on the application, namely the control of a power electronics converter. The Boost converter is widely used within energy storage and renewable energy. It can for instance be used for interfacing a super-capacitor bank with a constant voltage DC –bus. It can also be used for optimizing the power output of solar panels, so called maximum power point tracking.

## 2 Controller design

### 2.1 Description of the Boost converter

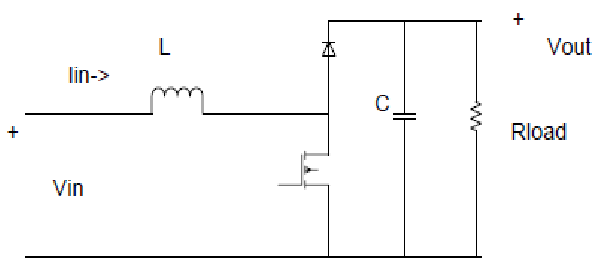


Fig. 1: Boost converter

The schematic of a power electronic Boost converter is shown in Fig. 1 [3]. The Boost converts DC to DC voltage and it is also called step-up converter. The output voltage is always higher than the input voltage. The relation between the input and the output voltage is changed by varying the duty cycle D in (1). In Fig. 1 the output is connected to a resistor, but this can also be another load, for instance a DC-bus or another converter.

$$\frac{V_{out}}{V_{in}} = \frac{1}{1-D} \qquad (1)$$

The Boost converter is often modeled using (2), where $x_1$ is the output voltage and $x_2$ the inductor current [7]. (2) can be linearized leading to (3) [4]. This equation is valid for small deviations from the operating point $\overline{x_1}, \overline{x_2}, \overline{D}$.

$$\begin{bmatrix} \frac{dx_1}{dt} \\ \frac{dx_2}{dt} \end{bmatrix} = \begin{bmatrix} 0 & -(1-D)\frac{1}{L} \\ (1-D)\frac{1}{C} & -\frac{1}{RC} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix} V_{in} \qquad (2)$$

$$\begin{bmatrix} \frac{dx_1}{dt} \\ \frac{dx_2}{dt} \end{bmatrix} = \begin{bmatrix} 0 & -(1-\overline{D})\frac{1}{L} \\ (1-\overline{D})\frac{1}{C} & -\frac{1}{RC} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} \frac{1}{L}\overline{x_2} \\ -\frac{1}{C}\overline{x_1} \end{bmatrix} D \qquad (3)$$

## 2.2 PI controller design

The transfer function for a PI controller is given in (4). For designing the PI controller Ziegler-Nichols method was used. This is an experimental method for deciding the parameters of a PID controller [4]. It would have been possible to design the controller based on the transfer functions of the system and the controller and suitable gain and phase margins. However, Ziegler-Nichols method accounts for modeling uncertainties as it was performed with the simulation file. The output voltage is 200 V for all simulations.

$$h_{PI}(s) = \frac{K_p s + K_i}{s} \qquad (4)$$

| Input voltage | $K_p$ | $K_i$ |
|---|---|---|
| 60 V | 8.1 | 27.4 |
| 180 V | 17.1 | 82 |

Table 1: Parameters PI

The result of Ziegler-Nichols method is shown in Table 1. The values differ significantly for different input voltages. The lowest bandwidth of the system is when the difference in input and output voltage is big. Parameters for the operating point with lowest input voltage must therefore be used.

## 2.3 Fuzzy logic controller design

Two different controllers using fuzzy logic have been designed; one PI controller tuned with fuzzy logic (FLC1) and one pure fuzzy controller (FLC2).

### 2.3.1 PI with fuzzy tuning (FLC1)

FLC1 has the same transfer function as (4), however with adjustable $K_i$ and $K_p$. The expression for $K_p$ is given in (5), where $u_{fl}$ is the output of the fuzzy controller (between 0 and 1). The two constants in (5) as well as the two input gains of the fuzzy controller part were optimized using genetic algorithms. To limit the number of constants to calculate, $K_i$ was set to $3.4K_p$ as this is the relation given by Ziegler-Nichols method (Table 1)

$$K_P = k_{offset} + k_{gain,fl} u_{fl} \qquad (5)$$

The rule base for FLC1 is given in Table 2 and illustrated in Fig. 2. The rule base is made based on the philosophy that the controller should be aggressive when the deviation is big. All the membership functions (MFs) are triangular apart from nb and pb that are trapezoidal. The MFs are equally distributed.

| **e\Δe** | **nb** | **nm** | **ns** | **zero** | **ps** | **pm** | **pb** |
|---|---|---|---|---|---|---|---|
| **nb** | vb | b | mb | mb | mb | b | vb |
| **nm** | b | mb | sb | s | sb | mb | b |
| **ns** | mb | sb | s | vs | s | sb | mb |
| **zero** | mb | s | vs | zero | vs | s | mb |
| **ps** | mb | sb | s | vs | s | sb | mb |
| **pm** | b | mb | sb | s | sb | mb | b |
| **pb** | vb | b | mb | mb | mb | b | vb |

Table 2: Rule base FLC1

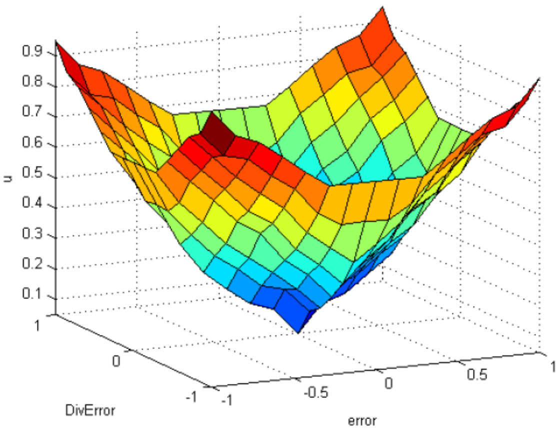


Fig. 2: Surface plot FLC1

To optimize the four parameters of FLC1 genetic algorithms were used. The fitness value was calculated with (6) where e is the error in output voltage and N the total number of samples.

$$f_{fitness} = \sum_{i=1}^{N} |e_i| \qquad (6)$$

A population of 20 was chosen, with Matlab default mutation, migration and cross over probabilities. The average fitness value as well as the best fitness value in every generation is plotted in Fig. 3. The error is coming down and converges.

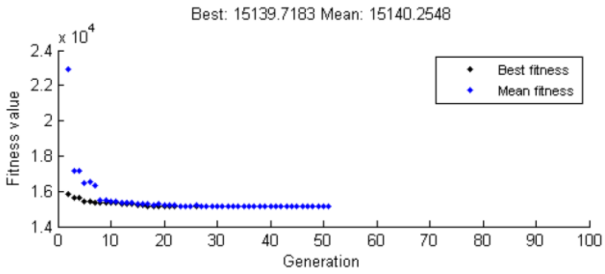


Fig. 3: Fitness value FLC1

### 2.3.2 Pure fuzzy controller (FLC2)

The schematic of the FLC2 is shown in Fig. 4. The controller consists of a PD fuzzy controller and an integrator in parallel. Generally derivative controllers are avoided when dealing with power electronics converters because the switching may disturb the D part of the controller. However, PD type are the normally used controllers for fuzzy logic and have proven to work well for power electronics too [5][6].

As seen in Fig. 4 there are four constants that need to be tuned in the FLC2; two input gains for the fuzzy controller, the output gain of the fuzzy controller and the output gain of the integral part. The limits of the saturation are set to a maximum duty cycle of 0.9 as for all controllers.

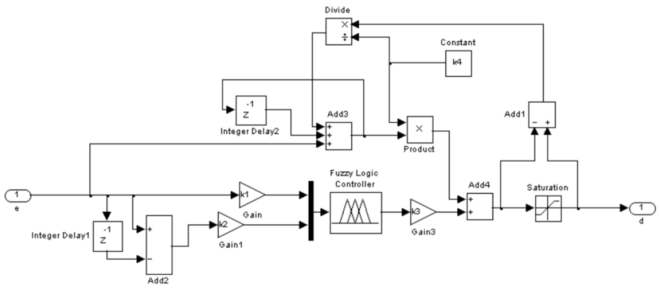


Fig. 4: Schematic FLC2

| e\Δe | nb | nm | ns | zero | ps | pm | pb |
|---|---|---|---|---|---|---|---|
| **nb** | nb | nb | nb | nb | nm | ns | zero |
| **nm** | nb | nm | nm | nm | ns | zero | ps |
| **ns** | nb | nm | ns | ns | zero | ps | ps |
| **zero** | nm | nm | ns | zero | ps | pm | pm |
| **ps** | ns | ns | zero | ps | ps | pm | pb |
| **pm** | ns | zero | ps | pm | pm | pm | pb |
| **pb** | zero | ps | pm | pb | pb | pb | pb |

Table 3: Rule base FLC2

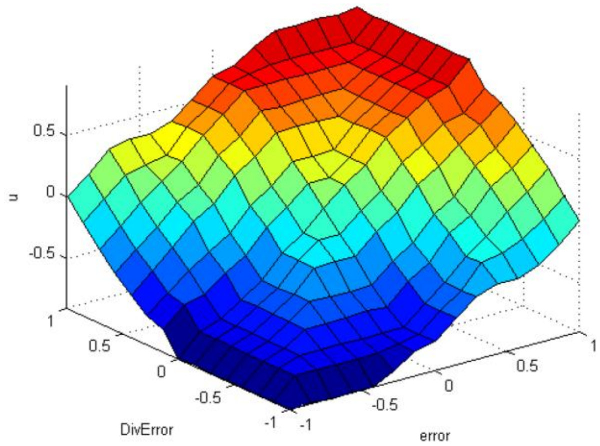


Fig. 5: Surface plot FLC2

The rule base and the surface plot of FLC2 are shown in Table 3 and Fig. 5 respectively. The parameters of the FLC2 were optimized in the same way as the FLC1. The fitness value is shown in Fig. 6. When compared to Fig. 3 it can be seen that the fitness value is significantly lower for the FLC2 than for the FLC1. This indicates that FLC2 is a better controller.

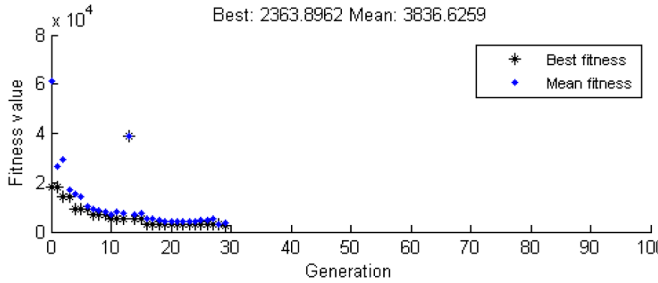


Fig. 6: Fitness value FLC2

## 3 Simulations

Simulations have been performed for the three controllers described in the previous section.

### 3.1 Description of simulation case

The controllers were all made to maintain the output voltage constant at 200 V. The simulation consists of a start-up for the converter and then a step in input voltage as perturbation after 0.5 seconds. Boost converters often work with variable input voltage and constant output voltage, for example converters for solar panels and super-capacitors. The parameters of the converter are given in Table 4. The size of L and C gives acceptable ripples for all operating points.

| Parameter | Value |
|---|---|
| L | 37 mH |
| C | 3300 µF |
| $R_{load}$ | 331 Ω |

Table 4: Parameters Boost converter

## 3.2 Simulation results

The simulation results are shown in Fig. 7. The input voltage is given in the first plot. The output voltage is given in the three next plots for PI, FLC1 and FLC2 respectively.

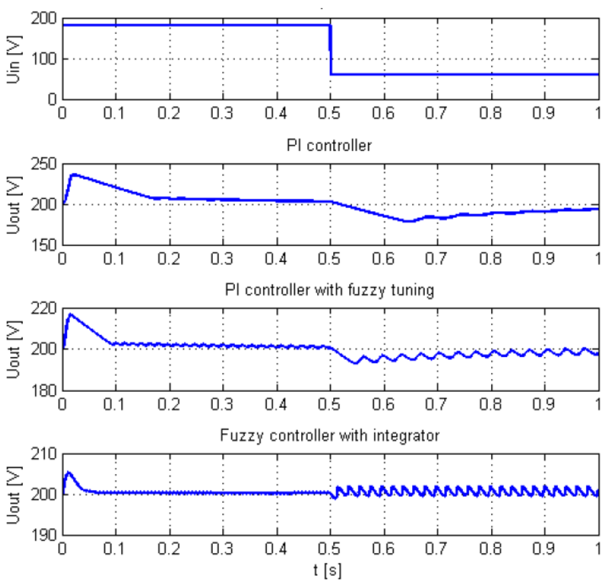


Fig. 7: Simulation results

The results for the PI controller are as expected. The output voltage falls as a result of the change in input voltage. It takes time to arrive at a higher input current and thus stabilizing the output voltage. The maximum deviation from the reference value for PI is in start-up, with 20 %.

The FLC1 is slightly better. The oscillations are expected because the FLC1 is PI controller that is more aggressive (higher $K_p$) than PI.

The FLC2 is the best of the three controllers. The deviation from the reference value is very small, only 3%. This is very little for power electronics converter. It is without doubt the controller with the best performance.

## 3.3 Details for FLC2

Simulation details for FLC2 are given in Fig. 8. The first plot is the input voltage perturbation equal to the plot in Figure 7. The $U_{out}$ is also equal to the plot in Figure 7. In Figure 8, however, $I_{in}$ is also shown. *Contr* is the output of the controller, the value that is being transformed into a PWM signal and sent to the switch. At the bottom the output of the fuzzy controller is shown. The variable is called *fuzzy*. We can see that oscillations appear everywhere in the controller loop. The reason for these oscillations needs to be further investigated.

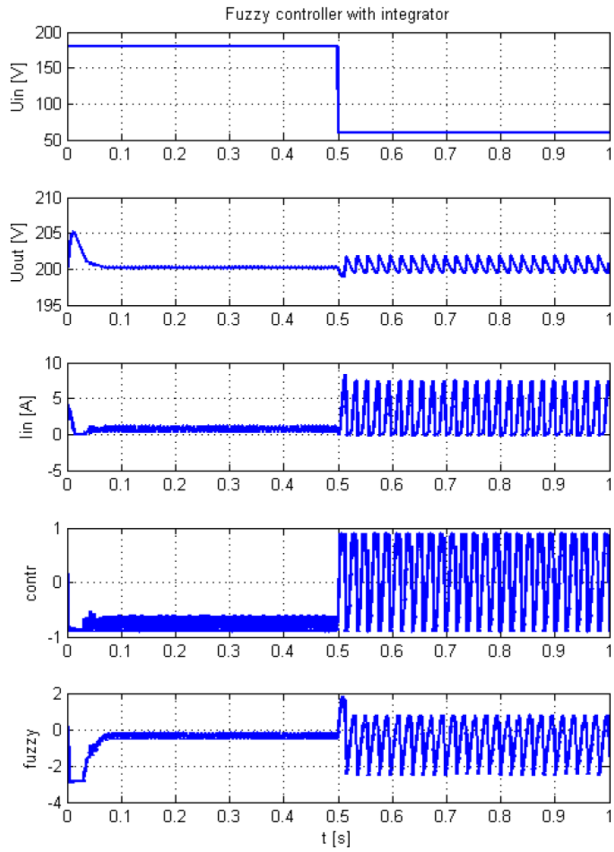


Fig. 8: Details FLC2

## 3.4 Robustness considerations

To test the robustness towards parametric changes simulations FLC2 were run for 10 %, 20 % and 30 % increase and decrease in L, C and R. At 10 % variation no difference was observed. For 20 % decrease in R large oscillations occurred in the output voltage (amplitude 50 V). At 30 % variation the simulations stopped because the anti wind-up became an algebraic loop. Robustness towards 10 % change in parametric values is a good. However, it is concerning if the controller cannot handle a change in R as this means a change in load. It is assumed that the error is caused by numeric problems in the simulation software and that it will not be a problem when the controller is implemented in a digital processor unit (DSP).

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# 4 Conclusion

Based on the results presented in this paper the FLC2 proves to be a powerful controller. The goal is to maintain a constant output voltage, and the FLC2 manages this much better than the two other controllers. The maximal deviation is only 3 % for FLC2 compared to 20 % for PI. FLC2 is also better than FLC1. The FLC1 can be said to be an optimal PI.

It is also seen that genetic algorithms are suited for optimizing the controller parameters. Transfer function theory is not valid for FLCs. One must therefore assure the stability in other ways, by testing different operating points and parametric variations. It is assumed that the FLC2 works best for systems with a repeated trajectory, like robots. It can also be useful for interfacing solar panels and super-capacitors with a DC-bus with constant voltage.

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