Controlling Switched Dc-Dc Converter Using ANFIS in Comparison with PID Controller

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Abstract. The non-linear behaviour of the Dc-Dc converters which appears mainly because of different causes such as disturbances, aging of materials, source instability which makes control process as a difficult task to overcome, many control techniques are employed such as PID controllers which works under linear operating conditions and fails with non-linear systems, so in order to reach a good dynamics, good performance and a good insensitivity to perturbations and parameter uncertainties, an artificial intelligence control strategy namely ANFIS has been used which does not need the mathematical model of the plant and automatically overcome the changing conditions as well. In this paper, a MATLAB / Simulink inspection is established to design a prototype model for such a converter with two different control principles (PID, and ANFIS) for Comparative purposes. In ANFIS controller two input parameters and one output (error signal, and rate of change in error) are considered, this voltage controller ensures better dynamic behaviour and superior performance compared to PID controller in regulating the output voltage.

1. Introduction
Power supplies are important devices for fulfilling the demands of many electrical devices which its main goal is to obtain a stable, high efficiency, with improved dynamic performances. As an efficient voltage regulator which can supply many electronic systems with output voltage less than (buck topology), more than (Boost topology), or less/more (Buck/Boost topology) voltage than the input voltage is the Dc-Dc converter. The Buck Dc-Dc converter is the topology where the output voltage Vo is less than the input voltage Vi depending on the controlling strategy considered, the basic block diagram of such converter is illustrated in Fig.1 [1].

Figure 1. Basic block diagram of Buck converter.
This converter has a nonlinear behaviour due to the parameter fluctuation and perturbations that can affect the stability of the converter, many approaches have considered overcoming this disadvantage such as PID controllers which is widely used but does not give satisfactory results because of they’re linear operating conditions [2], [3]. This approach needs the mathematical model which can be built from the basic circuit of the step-down converter which can be established from Fig.2.

**Figure 2.** Basic Buck converter circuit.

Another approach deals with the nonlinear system and needs no exact mathematical model called artificial neural network (ANN) which can ensure a stable operation in case of system parameter variation and requires a good realization of the system behaviour [4].

This approach implements the learning process, or the ability to of acquiring, storing, and using experiential knowledge to minimize error signal ($e$) which is the result of comparing the output voltage ($V_o$) and the reference voltage($V_{ref}$), resulting in dynamic response improvement to realize wanted dynamic specifications [5].

In the following paper we consider voltage control of a basic Buck converter using ANFIS strategy in comparison with the PID controller. A digital simulation using MATLAB/SIMULINK is obtained to realize the response of each controller and verify the different characteristics of the converter.

**2. Dc/Dc Buck converter Mathematical Model**

The mathematical model can be established depending on the switching process (ON, OFF) as can be seen in Fig.2, in the continuous conduction mode and using “Kirchhoff's Voltage law”, and “Kirchhoff’s current law”. Considering that D is the duty cycle which is equal to 0 in case of OFF status, 1 in case of ON status, we can now write the characteristic equations of Buck converter as [6]:

\[
\frac{di_L}{dt} = \frac{v_i - D}{L} - \frac{i_L R_L}{L} - \frac{v_o}{L} \tag{1}
\]

\[
\frac{dv_c}{dt} = \frac{i_L - v_o}{C} - \frac{i_o}{C} , \text{ where } i_o = \frac{v_o}{R_L} \tag{2}
\]

\[
v_o = v_c + r_c i_L - r_i i_o \tag{3}
\]

**Figure 3.** Open loop circuit for the Buck converter.
3. PID Controller
The basic idea of such controller is to minimize the error between a measured value and a desired one, each part of this controller has its own function, so the Proportional part controls the response to the present error, the Integral part controls the response based on total measured errors and the Derivative part controls the response derivative of the error has been changing. PID controller does not have the ability to learn, tuning of the controller is based on selecting gain values which can be tuned according to a “trial and error” approach. The PID controller is simple but it is not adequate for the Dc converters because it suffers from long rise time when overshoot of the input voltage decreases. The Buck converter based on PID controller can be estimated as in Fig.4:

![Figure 4. Converter with PID controller.](image)

4. Adaptive Neuro-Fuzzy Inference System

The neural network controllers are devices that require detail data about the converter, especially the number of inputs neurons which is equal to the input signals, also the output neurons which are equals to the output signals respectively, they have the ability of training with the help of known examples to obtain knowledge about a problem. The ANFIS is the combination of Fuzzy Logic technique and neural network technique to improve the quality of the output voltage of the converter, the structure of ANFIS consists of two inputs namely x and y and one output Z, a number of rules and five distinct layers (architecture of an ANFIS) as in Fig.5 [7], [8]:

![Figure 5. ANFIS structure.](image)

If we denote $A_i, B_i$ as fuzzy sets(input), $Z_i$ as system output, and $p_i, q_i, r_i$ as parameters collected during the learning process (designing parameters), so the first order Sugeno fuzzy inference with two inputs and two rules:

$$\begin{align*}
\text{Rule 1} & : \text{ if } x \text{ is } A_1 \text{ and } y \text{ is } B_1, \text{ then } Z_1 = p_1 x + q_1 y + r_1 \\
\text{Rule 2} & : \text{ if } x \text{ is } A_2 \text{ and } y \text{ is } B_2, \text{ then } Z_2 = p_2 x + q_2 y + r_2
\end{align*} \tag{4}$$

From Fig.5 we can notice the task of each layer as following:

**First layer** represents the input node where the node function is:
\[ O_i^1 = \mu_{A_i}(x), \ i = 1, 2 \]

\[ O_i^1 = \mu_{B_i}(x), \ i = 3, 4 \]  

The second layer points up the multiplication of all inputting signals, or in other words, the product of all signals which represents the output of this node and can be reduced to:

\[ O_i^2 = w_i = \mu_{A_i}(x) \cdot \mu_{B_i}(y), \ i = 1, 2 \]  

The output of this node represents the firing strength of one rule. The third layer in this layer the firing strength of \( i \) rule for \( i \) node is equal to the total of firing strength of all rules.

\[ O_i^3 = w_i = \frac{1}{w_1 + w_2}, \ i = 1, 2 \]  

Layer four in this stage, each \( i \) node estimates the values of weighted results. The resulting function is:

\[ O_i^4 = \bar{w}_i = \bar{w}_i \cdot (p_1x + q_1y + r_i), \ i = 1, 2 \]  

where, \( \bar{w}_i \) represents the output of layer 3 and a normalized firing strength, and parameter set \( \{pi, qi, ri\} \) represents the consequent parameters.

Layer five in this layer we have one node labeled as \( \sum \) which denote the total of all consequent signals for the system and can be expressed as:

\[ O_i^5 = \sum_{i=1}^{2} \bar{w}_i * f_i = \sum_{i=1}^{2} \frac{\bar{w}_i * f}{w_i} \]  

Finally, we can adopt the output as:

\[ z = \frac{w_1}{w_1 + w_2} f_1 + \frac{w_2}{w_1 + w_2} f_2 = \bar{w}_1 (p_1x + q_1y + r_1) + \bar{w}_2 (p_2x + q_2y + r_2) = \]

\[ = (\bar{w}_1 x)p_1 + (\bar{w}_1 y)q_1 + \bar{w}_1 r_1 + (\bar{w}_2 x)p_2 + (\bar{w}_2 y)q_2 + \bar{w}_2 r_2 \]  

5. Controlling the Buck converter

For this purpose, we use Fig.4 for controlling Buck converter with PID controller, and Fig.6 for controlling Buck converter with ANFIS controller that controls the duty cycle \( D \), the whole process is based on implementing MATLAB environment [9]. The ANFIS model structure allocated for this paper is demonstrated in Fig.7. From this figure we can conclude that the ANIFS structure for this paper consists of 39 fitting parameters, 12 as premise parameters, and 27 as consequent parameters. Using back-propagation approach we tune the membership function parameters for the fuzzy inference system (FIS), or this approach together with a least-squares approach.
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Figure 6. Close loop of controlling Buck converter with ANFIS controller.

Figure 7. Structure of ANFIS controller.

6. Simulation Results

In this section we will test the conventional Buck Dc/Dc converter (Fig.3), Buck Dc/Dc converter with PID controller (Fig.4), and converter with ANFIS controller (Fig.6), the element value is set as in Table.1. Using MATLAB/SIMULINK environment we can illustrate the output voltage of each of the converters.

Tabel.1 Elements value

| No. | element | Value     |
|-----|---------|-----------|
| 1   | $V_i$   | Input voltage | 50V   |
| 2   | $V_o$   | Output voltage | 15V   |
| 3   | $L$     | Inductance  | 1mH   |
| 4   | $C$     | Capacitance | 100µ   |
| 5   | $T$     | Sampling period | 1µs   |
| 6   | $F_s$   | Switching freq. | 5kHz   |
| 7   | $R_L$   | Output resistance | 4Ω   |
| 8   | $r_L$   | Inductor resist. | 80mΩ   |
| 9   | $r_C$   | Capacitance resist | 5mΩ   |
| 10  | $K_{p1}$ | Integral gain | 280   |
| 11  | $K_{p2}$ | Derivative gain | 0.001 |

Depending on Fig.3, and using components value from Table.1, the proposed simulated output voltage of the open-loop circuit of the Buck converter is shown in Fig.8. Also, the output voltage of the Buck...
converter with PID controller can be seen in Fig. 9. In Fig. 10 we illustrate the control circuit (ANFIS) added to the circuit of the converter, so the proposed simulation model for regulating the output of the converter is. Using MATLAB, Fig. 10, and Table.1, for a given input voltage, the proposed (simulated) output voltage of the Buck Dc/Dc converter can be shown in Fig. 11, the total specifications of the two controllers is enclosed in Table.2.
Figure 11. Dynamic response of the Buck converter with ANFIS controller.

The membership function for $e(k)$, and $du(k)$ are shown in Fig. 12.

![Membership function for e(k) and du(k)](image)

Figure 12. Inputs of ANFIS.

| Controller | Overshoot | Rising Time | Steady state |
|------------|-----------|-------------|--------------|
| PID        | 46%       | 0.00395     | 0.008        |
| ANFIS      | $\approx 0$ | 0.0003     | 0.0045       |

7. Conclusion
In this paper, controlling the resulting voltage of the step-down converter is considered, the first step is to test the PID controller, then we test the ANFIS controller. The comparison is fulfilled with MATLAB simulation, the results of simulation indicate that Adaptive Neuro-Fuzzy System (ANFIS) controller is better than the PID controller regarding performance and efficiency. The fuzzy controller has the main disadvantage with selecting the rules, membership functions, and scaling factors, this drawback can be modified using Neural Network to obtain satisfactory results. Finally, the ANFIS controlling method is an easy method and can obtain good results over the unbalanced voltage at the input and parameters variation leading to improved voltage regulation in the converter circuit, which enables us to implement this approach to different DC/DC converters topologies as future work.
8. References

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