Controlling DC-DC Buck Converter Using Fuzzy-PID with DC motor load

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Abstract. Circuit of DC-DC converter is a device converting from remains DC input voltage to variable output voltage. The components used for switching converter can be MOSFET, IGBT, Thiristor, GTO and others. This paper discusses DC-DC buck converter to reduce the voltage by using MOSFET switching that is used to control the output voltage of buck converter remain constant with DC motor load. To control the output voltage the buck converter remains constant and stable, it is required proper control to regulate the duty cyclenya. The methods are combination of conventional control methods namely Proportional Integral Derivatives (PID) and intelligent control of Fuzzy logic. It was simulated by using MATLAB software. The simulation results show the combination of PID control and Fuzzy Logic can improve the performance. Small error is almost zero and the output voltage of the buck converter remains constant even though the motor load is changed.

Keywords: Buck Converter, fuzzy PID kontroller, Motor DC

1. Introduction

To get an output voltage that has a high quality and efficiency, it usually uses a switching system rather than linear systems that have power losses. This paper discusses the control of output voltage DC-DC buck converter which serves to decrease the voltage till remain constant, when DC motor load is altered using MOSFET switching. Combination of PID control and Fuzzy logic are used that regulates their cycle duty. On switching converter,MOSFET, IGBT, Thiristor, GTO and others components are applied. PID method is a conventional control that has been widely used both for research and applications in the industry. While *Fuzzy like PD* is a fuzzy control intelligent whose behavior resembles PD.
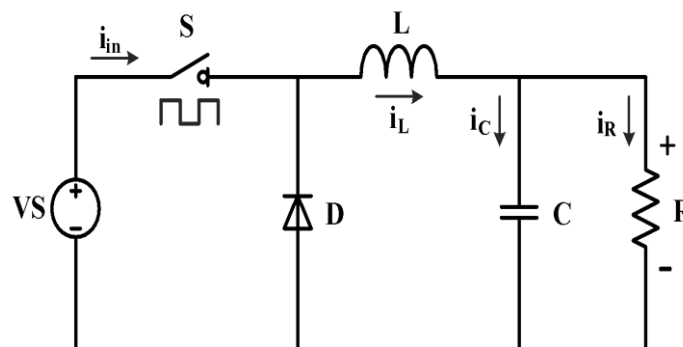

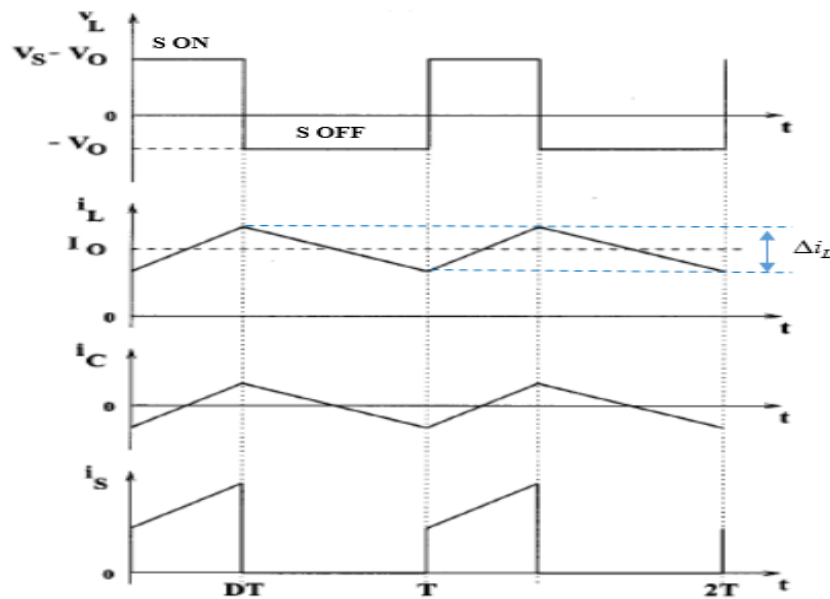
Fig 1. Buck converter circuit

Fig 2. Wave response of buck converter

Some studies that have been done related to buck converter control.Amit, et al. [1] discusses speed control driven by FOPID DC motor to see performance and robustness orvarying loads. Bhagyashri et al. [2] figure out load changes and input voltage reducing efficiency and power of the converter. The function of fuzzy control is to maintain the output voltage constantly even though the input and load voltages are changed in fast.Sutedjo et al. design construct DC-DC converter module with PI controller. It can control the output voltage of buck and boost converter circuit to be stabler even with the condition of input voltage is not balanced, when the circuit works [3]. Jumiyatun dkk., compare two methods; conventional PI method and Fuzzy-PI Logic to control the output voltage of buck converter remaining constant. Controlling using Fuzzy-PI controller is better performance and faster response than conventional method [4].

2. Method

In this study, DC-DC converter is designed by determining the correct parameters value of the main components of buck converter, namely inductor (L), Capacitor (C), Resistor (R), duty cycle, and DC motor instead of R load. During simulation, combination of Fuzzy logic control and PID performs better output steady state response.
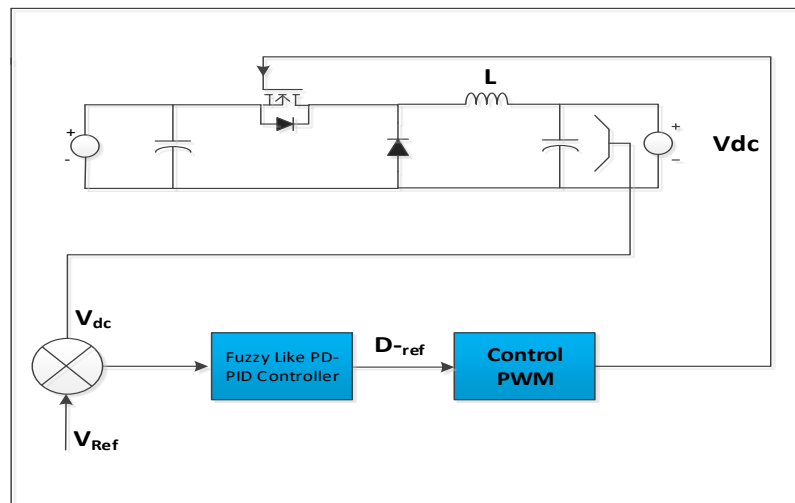
Fig 3. System diagram

As can be seen in Fig 3, the system diagram above the buck converter receives the input and current voltage from the DC source, then converts the output voltage lower than the input voltage and the result is fed to the load. Thus, the voltage that flows into the load can be valued according to the set point that has been determined and then output from buck converter in feedback to control.

a. Buck converter [5]

designing the system, the parameter values of each component of the buck converter as seen in Table must be set so that the whole system runs well.

Table 1. Parameters of buck Conventer

Parameter	Value
Input voltage (Vin)	500 Volt
Output voltage (Vo)	200 Volt
Ripple (ΔV)	5%
Arus Output (Io)	12 A
Ripple Arus (ΔI)	10%
Frekuensi Switching	10 KHz

- Determine of duty cycle values   (1)

$Son = Soff$

$(Vin - Vo)ton = Vo.toff$

$Vin.ton - Vo.ton = Vo.T - Von.ton$

$Vin.ton = Vo.T$

$$\frac{ton}{T} = \frac{Vo}{Vin}$$

$$D = \frac{Vo}{Vin} = \frac{200V}{500V} = 0,4$$

- Determine resistor value   (2)

$$R = \frac{Vo}{Io} = \frac{200V}{12A} = 16,667\Omega$$

- Determine inductor value   (3)

$$\Delta IL = 10\% \, x \, 12A$$
$$\Delta IL = 1,2A$$

$$L = \frac{Vin(1-D)D}{\Delta ILxfs}$$

$$L = \frac{500V(1-0,4).0,4}{1,2Ax10Khz}$$
$$L = 0,01H$$

- Determine capacitor value   (4)

$$\Delta V = 5\% \, x \, 200V$$
$$\Delta V = 10V$$
$$R = \frac{Vo}{Io} = \frac{200V}{12A} = 16,667\Omega$$

$$C = (D.Vin + \Delta V)\frac{(1-D)}{fs.R.\Delta V}$$

$$C = (0,4.500V+10)\frac{(1-0,4)}{10000x16,667x10}$$

$$C = 0,0000756 \; \mu F$$

Table 2. Parameters of Motor DC

Parameter	Unit(SI)
Mechanical power($P_{mekanik}$)	5 HP
Anchor voltage (E_s)	240 V
Nominal speed Nominal ($\omega_{nominal}$)	1220 Rpm
Anchor resistance (R_a)	0,6 Ω
Anchor current (I_a)	16,2 A
Anchor inductance (L_a)	0,012 H
Inertia (J)	I Kg.m^2

2.1. Designing controller method

To get the output voltage constant buck converter used to supply DC motor load using combination of Fuzzy like PD and PID control, the steps are as follows:
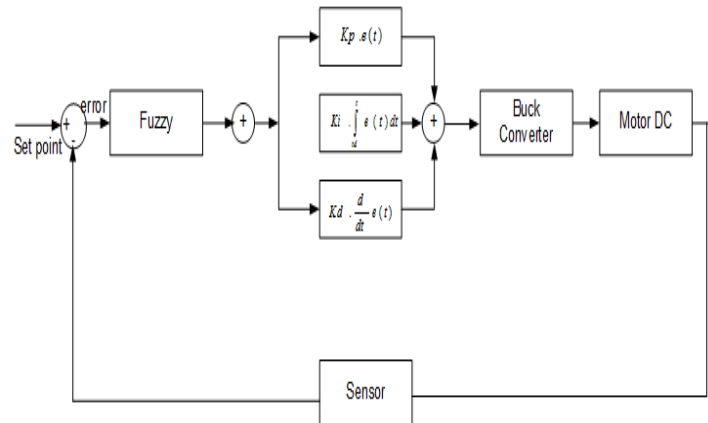

Fig 4. Block diagram of combination Fuzzy & PID Logic Control at Buck Converter with DC Motor Load

A. PID (Proportional Integral Derivative)[6]

Proportional Integral Derivative (PID) is a controller to determine the precision of an instrumentation system with the characteristics of feedback on the system. The PID control component consists of 3 types: Proportional, Integral and Derivative. All three can be used simultaneously or independently depending on the response we want to a plant. In the PID control, the error signal e (t) is the control input, while the control output is the control signal u (t). The relationship between the control input e (t) and the control output u (t) is:

$$u(t) = K_p \left\{ e(t) + \frac{1}{\tau_i} \int_0^t e(t) dt + \tau_d \frac{de(t)}{dt} \right\}$$
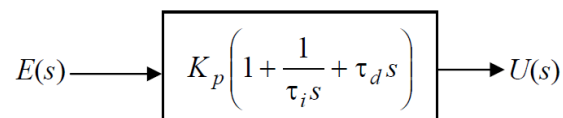
Or in form of Laplace Transformation :

$$U(s) = K_p \left(1 + \frac{1}{\tau_i s} + \tau_d s \right) E(s)$$

Thus, transfer function of PID controller is :

$$\frac{U(s)}{E(s)} = K_p \left(1 + \frac{1}{\tau_i s} + \tau_d s \right)$$

Block diagram of PID controller, namely :

$$E(s) \longrightarrow \boxed{K_p \left(1 + \frac{1}{\tau_i s} + \tau_d s \right)} \longrightarrow U(s)$$

which :
K_p = Proportional reinforcement
τ_i = Integral time
τ_d = Differential time

The function of the PID component is as follows:
1. Proportional control functions to accelerate the rise time.
2. Integral control functions to eliminate steady state errors.
3. Derivative control functions to improve system stability and reduce overshoot.

B.   Fuzzy like PD controller [7]**.**

Fuzzy like PD controller is a fuzzy controller that has a behavior resembling a PD controller. Design consists of the process of quantization, fuzzifikasi, inference, and defuzzifikasi. In the Fuzzy control type used in this design, the formation of Ke and Kde is used to normalize the boundary E and ΔE into the limit of -3 to +3. I used to denormalize the control signal limits from 0 s / d 3 to 0 s / d U_{max} or -3 s / d 3 to U_{min} s / d U_{max}. The design of the fuzzy control system is shown in Figure 5.
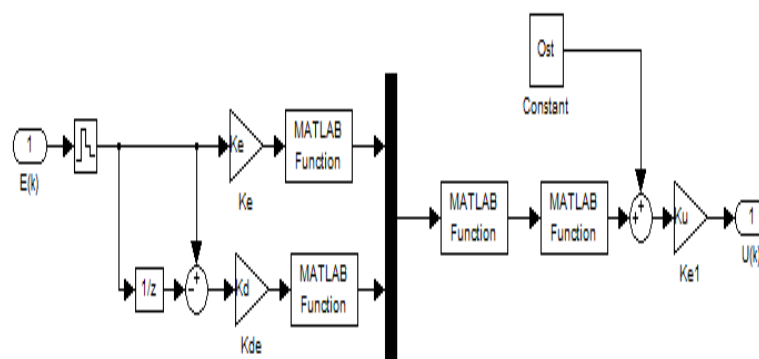

Fig 5. Block diagram of logic control on buck converter

Figure 6. A linear representation, membership level mapping that defines membership functions for E, ΔE and control signals in a normalized form on triangular shapes with 7 support sets.
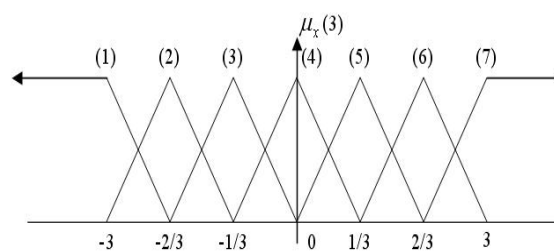

Fig6. Triangle function

Create a basic fuzzy rule that is used to determine the control signal with the help of inference. The preparation of fuzzy control rules with the membership set for each of the seven input entries is shown in Table 3.

Table 3. Preparation of Fuzzy Rules

E/dE	1	2	3	4	5	6	7
1	1	1	2	2	3	3	4
2	1	2	2	3	3	4	5
3	2	2	3	3	4	5	5
4	2	3	3	4	5	5	6
5	3	3	4	5	5	6	6
6	3	4	5	5	6	6	7
7	4	5	5	6	6	7	7

Inference here is Mamdani methods in which the equation is:

$$\mu_y(k) = \max\left[\min\left\{\mu_u(k), \mu_R(E(i), \Delta E(j))\right\}\right]$$

To get values of action control (u) , it needs defuzzification process that is calledCOA (*Center Of Area*).

3.   Results and Discussion

The simulation test of DC-DC buck converter with DC motor load with load variation using Fuzzy-PID control is shown on the response graph below:
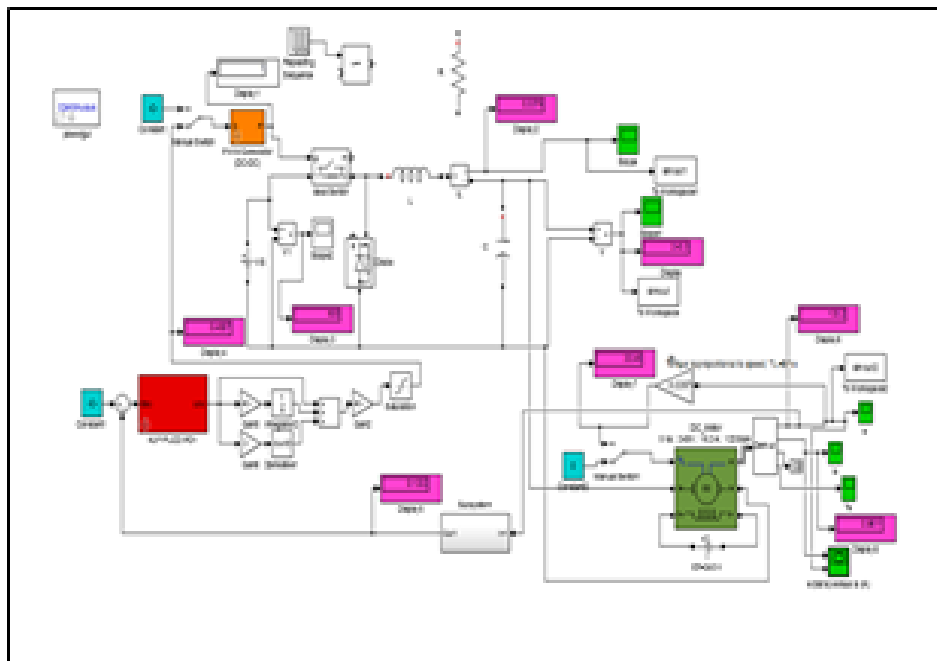

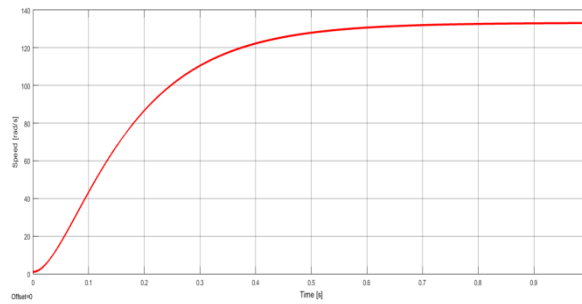Figure 7. Image Simulation of whole Buck Converter with DC Motor Load Using Fuzzy Control - PID.

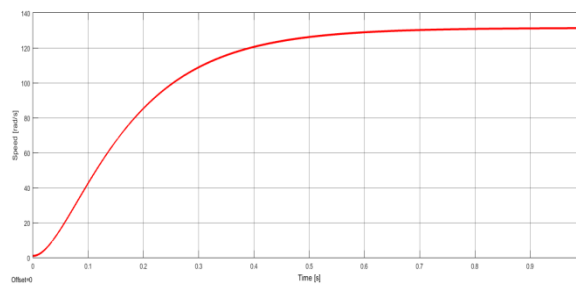Figure 8.Response on zero load and nominal speed (ωnom) = 133.2 rad / s

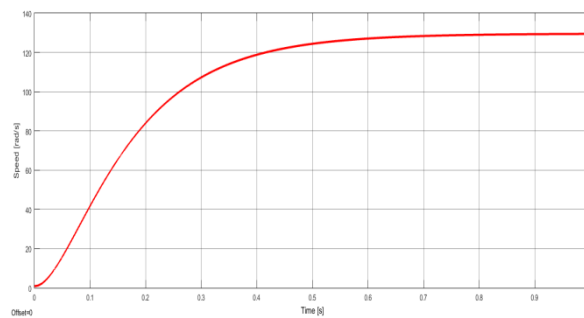Figure 9.Response on Load 10 and nominal speed (ωnom) = 131.3 rad / s

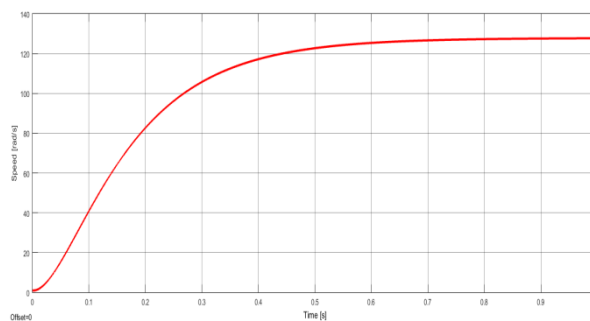Figure10.Response on Load 20 and nominal speed (ωnom) = 129,4 rad / s

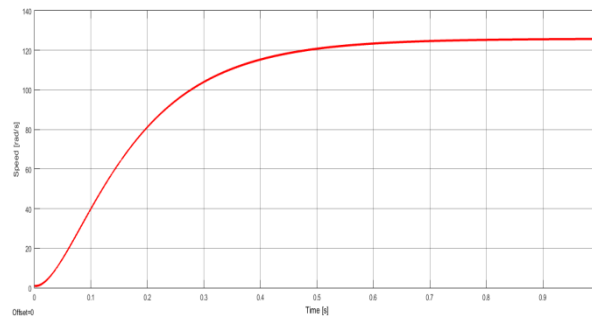Figure 11.Response on Load 29,2 and nominal speed (ωnom) = 127,7 rad / s

Figure 12.Response on Load 40 and nominal speed (ωnom) = 125,7 rad / s

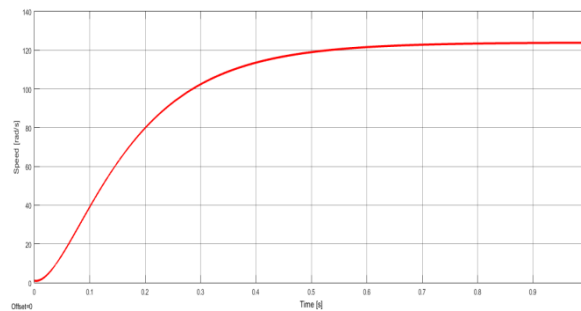Figure 13.Response on Load 50 and nominal speed (ωnom) = 123,9 rad / s

Table 4. Testing on Open Loop

V.Input (v)	V.Output (v)	Torse(Load)	Nominal Speed (rad/s)
500	240,2	0	133,1
500	239,9	10	131,3
500	239,9	20	129,4
500	239,8	29,2	127,7
500	239,8	40	125,7
500	239,8	50	123,8

Table 5. Testing of suing Fuzzy-PID controller

V.Input (v)	V.Output (v)	Torse(Load)	Nominal Speed (rad/s)
500	240,3	0	133,2
500	240	10	131,3
500	240	20	129,4
500	240	29,2	127,7
500	240	40	125,7
500	240	50	123,9

4. Conclusion

The simulation result of controlling buck converter with DC motor load using Fuzzy-PID control with load variation shows better performance than when open loop. The output voltage of the buck converter remains constant at 240 volts although the load is variable, in which the nominal speed of the motor follows the given load.

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