Simulation comparison of proportional integral derivative and fuzzy logic in controlling AC-DC buck boost converter

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Abstract - AC-DC converter is widely used in the commercial industry even for daily purposes. The AC-DC converter is used to convert AC voltage into DC. In order to obtain the desired output voltage, the converter usually has a controllable regulator. This paper discusses buck boost regulator with a power MOSFET as switching component which is adjusted based on the duty cycle of pulse width modulation (PWM). The main problems of the buck boost converter at start up are the high overshoot, the long peak time and rise time. This paper compares the effectiveness of two control techniques: proportional integral derivative (PID) and fuzzy logic control in controlling the buck boost converter through simulations. The results show that the PID is more sensitive to voltage change than fuzzy logic. However, PID generates higher overshoot, long peak time and rise time. On the other hand, fuzzy logic generates no overshoot and shorter rise time.

1. Introduction
The higher level of welfare of the population is directly proportional to the increasing demand for electrical energy. Today many consumers of electric power use electronic power converters such as uninterruptible power supply (UPS), charger, and electric regulator in low voltage channels. Various types of converters have been widely used in those converters.

AC-DC converters generally have three steps of working: rectifying, filtering, and regulating. The first stage aims to rectify AC voltage into DC voltage. The second stage is to smooth the DC voltage. The third stage is to regulate the output voltage (V_{out}) [1]. There are several regulating techniques employed by AC-DC converters, one of them is buck converter. Buck converter works when the output voltage is smaller than the input voltage. If the output voltage is greater than the input voltage, the converter is called the boost converter. If the output voltage is larger or smaller than the input voltage, the converter is called buck boost converter [2].

Control techniques are increasingly important nowadays in the buck boost converters due to their rapid responses and high accuracies. In previous studies, the proportional integral (PI) control method was used on an AC-DC buck boost converter to improve the power factor [4]. The open loop sliding control (OLSC) method is used on buck and AC-DC buck boost converters to improve total harmonic distortion (THD) and power factor [5]. The fuzzy logic control method is used on boost converter to regulate the output voltage and to improve the power factor [6]. The hysteresis current controller (HCC) method is compared to the fuzzy logic method on boost converter to regulate the output voltage, to improve THD and power factor on the input side [7]. This paper compares the effectiveness of PID and fuzzy logic in controlling pulse width modulation (PWM) on MOSFET switch to regulate output voltage based on reference voltage or desired voltage.
2. Research Methodology
This paper evaluates the AC to DC converter with diode bridge rectifier with a power MOSFET as a switching component that controlled by PWM signal through simulation. The magnitude of the output voltage is set according to the duty cycle (D) of PWM. If D > 0.5, then the output voltage (V_{out}) will be greater than the input voltage (V_{in}). Whereas if D < 0.5 then the output voltage will be smaller than input voltage, and V_{in} = V_{out} at D = 0.5 [3]. This paper evaluates varying values of duty cycle.

The circuit is modeled as depicted in Figure 1. The PID and fuzzy logic on buck booster converter is applied to feedback output voltage to MOSFET.

![Figure 1. Circuit diagram of AC-DC buck boost converter with control system](image)

2.1. Parameters of Simulation
Table 1 contains the parameters used in the simulation circuit. Source voltage is set 220 V with frequency of 50 Hz. The reference voltages are at 200, 225 and 250 Volts. Parameters of diode, MOSFET and capacitor are also shown in Table 1.

| Parameter                      | Value       | Unit    |
|-------------------------------|-------------|---------|
| Source voltage (V_{in})       | 220         | Volt    |
| Source Frequency (F)          | 50          | Hz      |
| V_{reference}                 | 200, 225 dan 250 | Volt |
| **Rectifier Diode**           |             |         |
| Resistance Ron                | 0.1         | Ω       |
| Forward voltage               | 0.8         | Volt    |
| Snubber resistance            | 500         | Ω       |
| Snubber capacitance           | 250 x 10^{-3} | F   |
| **Filter capacitor**          | 2.3 x 10^{-3} | Farad |
| **MOSFET**                    |             |         |
| Resistance Ron                | 0.1         | Ω       |
| Internal dioda resistance     | 0.01        | Ω       |
| Snubber resistance            | 1 x 10^{5}  | Ω       |
| Inductor                      | 1 x 10^{-3} | Henry  |
| **Diode regulator**           |             |         |
| Resistance Ron                | 0.1         | Ω       |
| Forward voltage               | 0.8         | Volt    |
| Snubber resistance            | 500         | Ω       |
| Snubber capacitance           | 250 x 10^{-3} | F   |
| Regulator capacitor           | 12 x 10^{-3} | Farad |
| Load R                        | 50          | Ω       |
2.2. Simulated Circuit with PID Control
The overall model of AC-DC buck boost converter circuit with PID control is shown in Figure 2.

![Figure 2. Simulated circuit of AC-DC buck boost converter with PID control](image)

Simulation with PID control uses one input error (e) of voltage and produces an output voltage as expressed in Equation (1).

\[ e(t) = V_{\text{eff}} - V_o \]  

(1)

The input error (e) of the voltage is processed each by multiplying it by proportional constant \( K_p \), integral constant \( K_i \), and derivative constant \( K_d \) then the result is summed to produce the output voltage. The expressions for the voltage error, proportional constant, integral constant and derivative constant are shown in Equations (2), (3), and (4), respectively.

\[ P_{\text{out}} = K_p e(t) \]  

(2)

\[ I_{\text{out}} = K_i \int_0^t e(\tau) d\tau \]  

(3)

\[ D_{\text{out}} = K_d \frac{de(t)}{dt} \]  

(4)

2.3. Simulated Circuit with Fuzzy Logic Control
The model of the AC-DC buck boost converter with fuzzy logic control is shown in Figure 3.

![Figure 3. Simulated circuit of AC-DC buck boost converter with fuzzy logic control](image)
The simulation with fuzzy logic control consists of two inputs: error $e(k)$ and derror $\Delta e(k)$. Error $e(k)$ is the difference between the desired voltage ($V_{\text{ref}}$) and the output voltage ($V_{\text{out}}$), while the derror $\Delta e(k)$ is the difference between the current error and the previous error shown in Equations (5) and (6), respectively.

$$
e(k) = V_{\text{ref}} - V_{\text{out}}(k) \quad (5)$$

$$
\Delta e(k) = e(k) - e(k-1) \quad (6)
$$

3. Results of Simulation and Discussion
The results of the simulation using PID and fuzzy logic control systems on AC-DC buck boost converter with $V_{\text{ref}}$ of 200 V are shown in Figure 5 and Figure 6.

Figure 4. Voltage wave and output current for $V_{\text{ref}}$ of 200 V with PID control

Figure 5. Voltage wave and output current for $V_{\text{ref}}$ of 200 V with fuzzy logic control
Based on the results, each control system is able to maintain the power factor value (cos $\phi$) on the input side and the output voltage based on the desired voltage $V_{ref}$. However, the differences are apparent in the characteristics of output currents and output voltages, i.e. overshoot, peak time, and rise time which can be seen in Table 2.

Table 2. Comparison of PID control and fuzzy logic control.

| No | Characteristic | $V_{ref} = 200$ V | $V_{ref} = 225$ V | $V_{ref} = 250$ V |
|----|----------------|------------------|------------------|------------------|
|    | V ref         | PID              | Fuzzy logic      | PID              | Fuzzy logic      |
| 1  | Rise Time     | 0.079 ms         | 0.04 ms          | 0.14 ms          | 0.04 ms          |
| 2  | Peak Time     | 0.145 ms         | -                | 0.24 ms          | -                |
| 3  | Max Overshoot $V_{out}$ | 217.9 V       | -                | 252.5 V          | -                |
| 4  | Min Overshoot $V_{out}$ | 201.5 V      | -                | 226.1 V          | -                |
| 5  | Max Overshoot $I_{out}$ | 4.35 A         | -                | 5.05 A           | -                |
| 6  | Min Overshoot $I_{out}$ | 4.03 A         | -                | 4.52 A           | -                |

Table 2 proves that by using PID control on AC-DC buck boost converter, the overshoot and peak time in voltage and current of output remain exist. The larger the $V_{ref}$ is given, the greater the values of overshoot and peak time are obtained. While using fuzzy logic control, overshoot does not exist, and the peak time does not occur.

The value of rise time generated by the PID is not constant and increasing to references voltage. Whereas by using fuzzy logic control, the value of rise time remains constant.

4. Conclusions

Based on the conducted simulation and parameters, fuzzy logic performs better than PID. PID control on the simulated AC-DC buck boost converter still generates the overshoot in the output voltage wave and output current. Its rise time and peak time increase to reference voltage.

On the other hand, the simulated AC-DC buck boost converter with fuzzy logic suppressed the overshoot on output voltage and output current. Peak time does not occur as there is no overshoot. Further, rise time is constant to reference voltage and shorter than the PID control.

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