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Intelligent Voltage Controller Based on Fuzzy Logic for DC-DC Boost Converter

Abstract*. One of the photovoltaic (PV) applications is as a renewable energy source. The photovoltaic (PV) output voltage becomes the voltage source for the DC-DC boost converter. To adjust the DC-DC boost converter's output voltage, the control system needs to adjust the output voltage of the DC-DC boost converter applied by the PV. The voltage generated by the DC-DC boost converter follows the needs of the electrical equipment or load. The control system on the DC-DC converter uses a Proportional Integral (PI) Controller and a Fuzzy Logic (FL). The PI controller and FLC can control the output voltage of the DC-DC converter. This PI controller is compared with FL to obtain the appropriate output voltage for the dc-dc boost converter. The output of this PI and FLC controller system is the duty cycle used to control the DC-DC boost converter's performance. The PI controller system is tuned by autotuning and FL to obtain control parameters of a DC-DC boost converter with a 12 V PV voltage source and a 24 V output voltage. The results of the PI controller constants obtained are: k_p = 1.8, k_i = 0.9, maximum overshoot voltage (Mp) = 39 V (62.25%), rise time = 1.0 seconds, settling time = 5.0 seconds, transient state = 5.0 seconds, and steady-state error of 8.4%. The simulation results of the FL controller constants were obtained: 4.2% steady-state error and a settling time of 1.5 seconds, with a 4.2% steady-state error. The results of the control output voltage DC-DC boost converter fed by PV showed FL was better than the PI controller.*

Streszczenie. *Jednym z zastosowan fotowoltaicznych (PV) jest odnawialne zrodlo energii. Napiecie wyjsciowe fotowoltaiki (PV) staje sie zrodlem napiecia dla prztwomicy podwyzszajacej DC-DC. Abywyregulowac napicie wyjsciowe przetromicy podwyzszajacej DC-DC, system sterowania musi wyregulowac napieciewyjściowe przetwornicy podwyższającej DC-DC, system sterowania musi wyregulować napięcie wyjściowe przetwornicy podwyższającej DC-DC stosowanej przez PV. Napięcie generowane przez przetwornicę podwyższającą DC-DC odpowiada potrzebom sprzętu elektrycznego lub obciążenia. System sterowania w przetworniku DC-DC wykorzystuje sterownik proporcjonalno-całkujący (PI) i logikę rozmytą (FL). Kontroler PI i FLC mogą sterować napięciem wyjściowym przetwornika DC-DC. Ten regulator PI jest porównywany z FL w celu uzyskania odpowiedniego napięcia wyjściowego dla przetwornicy podwyższającej DC-DC. Wyjściem tego systemu kontrolera PI i FL jest cykl pracy używany do sterowania wydajnością przetwornicy DC-DC boost. System regulatora PI jest dostrajany przez autotuning i FL w celu uzyskania parametrów kontrolnych przetwornicy podwyższającej napięcie DC-DC ze źródłem napięcia PV 12 V k_i napięciem wyjściowym 24 V. Otrzymane wyniki stałych regulatora PI to: k_p = 1,8, k_i = 0,9, maksymalne napięcie przeregulowania (Mp) = 39 V (62,25%), czas narastania = 1,0 s, czas ustalania = 5,0 s, stan przejściowy = 5,0 s, błąd stanu ustalonego 8,4%.* Uzyskano wyniki symulacji stałych regulatora FLC: błąd stanu ustalonego 4,2% i czas ustalania 1,5 sekundy z błędem stanu ustalonego 4,2%. FL był lepszy od kontrolera PI. (***Inteligentny kontroler napięcia oparty na logice rozmytej dla konwertera doładowania DC-DC***)

Keywords: control parameters, DC-DC boost converter, proportional integral controller, fuzzy logic
Slowa kluczowe: parametry sterowania, przetwornica doladowania DC-DC, proporcjonalny regulator calkujacy, logika rozmyta

Introduction

In recent years, Indonesia has faced a fuel oil crisis since domestic use of fuel oil by motorized vehicles and other purposes exceeds local output. Indonesia has turned become a gasoline importer. Limited fossil fuel energy sources, such as fuel and coal, drive the need for innovation to overcome future energy crisis challenges. The abundance of solar energy sources in Indonesia, which is located in the tropics, is an alternative energy solution worth examining with other renewable energy sources. Several renewable energy sources, including solar energy using photovoltaic (PV), have been developed in Indonesia in recent years as an alternative to energy sources such as fuels and fossil fuels. A system to manage the voltage and output power of the PV to maximize the electricity generated is one component of PV development. Solar energy has emerged as a realistic alternative that may be developed in Indonesia as a sustainable energy source, thanks to advancements in battery and PV technology. In PV applications, there are issues with the performance of the DC-DC converter. When the temperature of the PV and the intensity of solar power radiation fluctuate, the resultant voltage often varies. The voltage source for the DC-DC boost converter is the PV output voltage. As a result, a control technique to modify the voltage output of the DC-DC boost converter coupled to PV is required such that the resultant dc voltage fulfills the criteria is required.

The output voltage of the DC-DC converter may be controlled by the PI controller and FL. The duty cycle used to control the performance of the DC-DC boost converter is determined by the output of this PI control system and FL. The duty cycle value of the PWM governs and influences the dc-dc boost converter's output voltage [3-5]. Formalized paraphrase According to a closed-loop control system, unit step response has four main characteristics: rising time, settling time, overshoot, and steady-state error [6]. In this study, a PI Controller Fuzzy Logic Controller was utilized to manage the output voltage of a DC-DC boost converter, which increased the control system's improvement performance. The DC-DC boost converter's control system output voltage necessitates modeling, as does the controller selection.

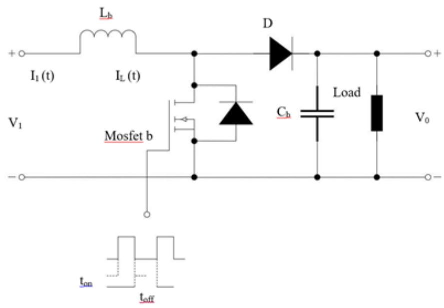

Fig 1. Circuit of DC-DC Boost Converter

DC-DC Boost Converter

The DC-DC Boost Converter is made up of a MOSFET, which is a metal oxide semiconductor, as well as diodes, inductors, and capacitor. The output voltage of the DC-DC Boost Converter is affected by the running duration. The output stress exceeds the input voltage. The working framework was centered on MOSFET switching functionalities for a DC-DC Boost Converter. The DC-DC

Boost Converter is seen in Figure 1[10-12, 20].

For the ideal boost converter, an illustration of how the transfer model may be employed in the case of a continuous conduction mode (ccm) is chosen [13].

To determine the design specification of the DC-DC boost converter, the input of the boost converter is essential. Table 1 shows the specification of the DC-DC boost converter [24].

Table 1 DC-DC Boost Converter Parameter.

Parameter	Value	Unit
Input Voltage	12	V
Capacitor	10^{-6}	F
Inductor	10^{-2}	H
Resistor	100	Ohm

DC-DC Boost Converter Continuous Conduction Mode

As previously stated, every power converter and its bilinear form may be acquired in one of two ways:

a) Generate a list of all conceivable configurations and look for common bilinear-led structures.

According to the preliminary study, a DC-DC boost converter running continuous conduction mode (ccm) might employ the configuration indicated in figure 2: case (a) and case (b), where switches H are on (h_1=1) and off (h_2=1), respectively. Because this is a DC-DC boost converter example, the switching feature maybe changed in two ways to u = h_1 = 1-h_2. Status variables include current i_L And capacitor voltage V_c. State-space equation (1)[13,21].

b. Identification of variables transferable

At first, a state variable is chosen. The I_L and V_C are status variables in the same way that they were in the previous method. The switchover variables in this example are the transistor voltage v_H and i_D current, which may be input as a function of the variable's state.

The transferred variable must also be expressed as a function of a properly stated switching function. As a switching feature, the following was added:

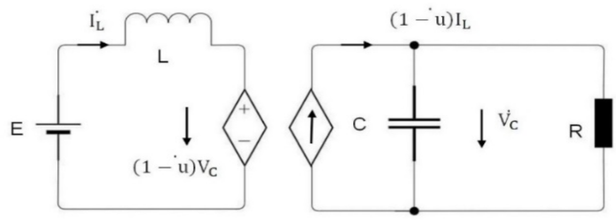

Fig 2. Equivalent circuit of DC-DC boost converter operating in ccm

$$\begin{cases} \dot{i}_L = -\frac{(1-u)V_C}{L} + E/L \\ \dot{V}_C = (1-u)i_L/C - \frac{V_C}{RC} \end{cases} \quad (1)$$

The bilinear form described by the equation may be derived in the same way as equation (2) can (3). Figure 2 shows the exact equivalent circuit of the Equation boost converter (2) in ccm regardless of the approach employed to deduce a bilinear form. The connection between the input and output circuits is described by two dependent sources. It works as an ideal DC transformer with a changeable ratio that may be regulated externally. The one-of-a-kind program enables simulation of the system described by Equation (1). The efficiency of the optimal thrust level as modelled by Simulink® in the phase shift of the duty cycle ratio [13

Proportional Integral (PI) Control System

The Proportional Integral (PI) controller is a common control scheme. The PI controller system block combines two proportional and integral control actions. Each one is advantageous since each proportional control action has the advantage of quickly expanding time. The integrated control operation has the advantage of lowering error. The goal is to combine these two control measures to control system production with a small error and a quick increase in time [23]. The PI block diagram is as follows [16-18

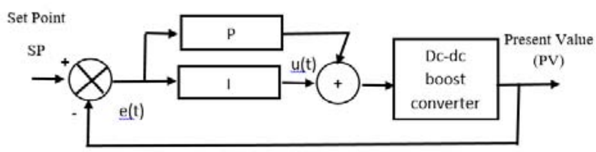

Fig 3. The PI Control System

Fuzzy Logic Controller

Professor Zadeh was the first to establish Fuzzy Logic in 1965. He evolved Boolean Set Theory (0 and 1) into sets with an undefined (between 1 and 0) member's meaning, commonly known as a fuzzy logic theory, by describing mathematical computations. The Fuzzy Logic Controller (FLC) is an artificial intelligence control system that operates on changeable considerations based on many roles. This method produces results faster than other smart control strategies such as genetic algorithms and neural networks. Fuzzy Logic controllers use several inputs to generate diverse control signals. The FLC input was selected depending on the frequency fluctuation. The input and output of a Fuzzy Logic controller correspond to a membership function.There are two possible inputs:error indicating the FLC system's selected input [14-15].

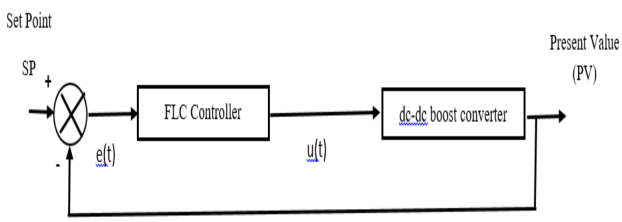

Fig 4. Fuzzy Logic Control

The system process constant value of FL controller system parameters using a fuzzy logic controller necessitates adjusting the values of the parameters based on the reading of the error e (t) and delta error e (t) of the output voltage. Error readings are used to determine whether it is necessary to change the constant values of the controller system parameters. If the error value is close to zero or the DC-DC boost converter's output voltage has converged, the obtained constant values of the FL controller system parameters will be preserved. However, if the error value is not yet close to zero or the output voltage of the DC-DC boost converter has not yet reached convergence, the FL constant values will be different and the constant values of the FL controller system parameters need to be re-tuned according to the rules that have been set [22].

The Mamdani Model for Fuzzy Logic Controller

On this research used the Mamdani model for Fuzzy Logic Controller. A rule R_i is stated as: in order to create a Mamdani fuzzy logic with a compact rule basis, a principal

If X_1 is A_{1j1} and X_2 is A_{2j2}……………..…., then U is w_{ik} Bk
A_{lji} and B_k , i = 1... n, j_l = 1... n_l, k = 1... m, are fuzzy sets associated with the n fuzzy input variables, each partitioned into n_j fuzzy sets, and the fuzzy output variable, each partitioned into m fuzzy sets, respectively. w_{ik} is a binary variable that specifies the rule's outcome, with subscript i denoting the rule and subscript *k* denoting the output fuzzy set. *w_{ik}* is a binary variable that decides the rule's outcome, where subscript *I* denotes the rule and subscript *k* denotes the output fuzzy set,*i = 1...r, k = 1... m, with r = n_1 x n_2 x* n_n; the total number of candidate rules.

As a result, *if w_{ik} = 0∀k, k = 1... m,* rule *i* has no effect and will be removed from the controller rule base.

Equations for error steady state (2), Δ error (3) and percentage of overshoot (4) are reported in [22].

(2) $$e(t) = \frac{\omega_{ref} - \omega_{measured}}{\omega_{ref}}$$

(3) $$\Delta e(t) = \frac{\Delta e(t)}{\Delta t} = e(t) - e(t-1)$$

(4) $$\%\,\text{Overshoot Maximum}\ (M_p) = \frac{M_p - V_\sim}{V_\sim} \times 100$$

Results

In this research, the continuous conduction mode DC-DC boost converter is the object of control using a PI controller and a Fuzzy Logic controller. The PI controller and Fuzzy Logic controller output characteristics with the control indicator of the DC-DC Boost converter. The control output indicators are the maximum overshoot value, steady-state error, rise time, and settling time. The simulation results of the control system output voltage dc-dc boost converter with a PI controller are shown in Figure 6. The purpose was to use the PI Controller to tune the values of k_p *and* τ_i on the PI Controller to obtain control results.

The simulation results show that the PI controller constants are k_p = 1.8 and τ_i = 0.9. The control system characteristics of the PI controller are tweaked to get the control parameters of the DC-DC boost converter with a 12 V PV voltage source and 24 V DC-DC boost converter output voltage.

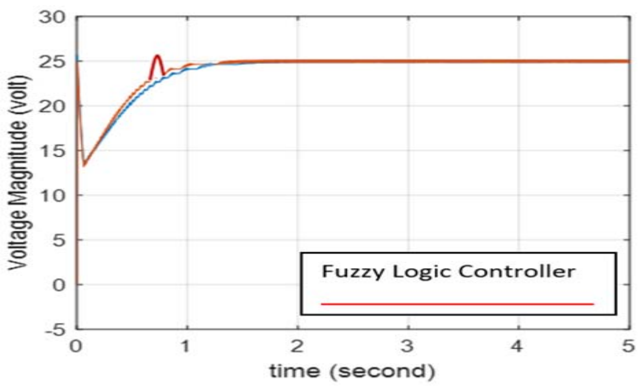

Fig 5. Fuzzy Logic Controller simulation results of the output voltage DC-DC boost converter

Table 2. Parameters Control DC-DC boost converter comparison of PI and FL Control

Parameters	PI Controller	FL Controller
Maximum over shoot (V,%)	33 V(37.5%)	26 V(8.3%)
Rise time (second)	1.0	0.8
Settling time (second)	5.0	1.5
Transient state(second)	5.0	1.5
Steady state error(%)	8.4	4.2

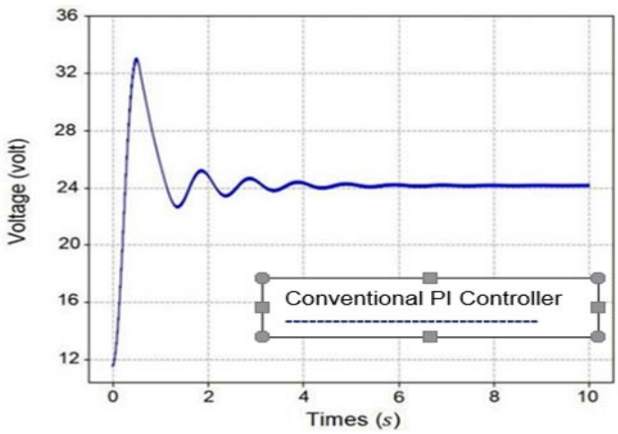

Fig 6. Conventional PI Controller simulation result of the output voltage DC-DC boost converter.

Conclusion

The DC-DC boost converter output voltage control system with a PI controller and a Fuzzy Logic controller can be used to determine the control parameters of the control system circuit. The results of the conventional PI controller constants obtained are: k_p = 1.8, τ_i = 0.9, maximum overshoot voltage (M_p) of 33 V (37.5%), rise time of 1.0 seconds, settling time of 5.0 seconds, transient state of 5.0 seconds, and steady-state error of 8.4%. The Fuzzy Logic Controller results are maximum overshoot voltage (Mp) of 26 V (8.3%), rise time of 0.8 seconds, settling time of 1.5 seconds, transient state of 1.5 seconds, and steady-state error of 4.2%. The results of control voltage DC-DC boost converter output fed by PV showed FL was superior better than the conventional PI controller.

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