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# Optimal Conversion of DC-DC Converter Considered Optimal Switching Time and Optimal Switching Mode of PWM by Fuzzy based PID Tuning

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***Abstract:*** ***This paper deals with design method of fuzzy controller for improving efficiency of DC-DC power converter. To design optimal control by fuzzy, this paper introduces optimal switching time and optimal switching mode of PWM. DC-DC Power converter is one of energy conversion device to transfer DC input source to DC output. When they transfer DC to DC, they have been using PID controller or fuzzy controller. Therefore, the efficiency of DC conversion strongly depends on PID parameter. Some papers illustrate tuning method of PID controller for this but have not been mentioning about the switching time and switching mode that can influence on the efficiency of DC-DC conversion. This paper suggests effective DC-DC conversion method by means of introducing switching time and switching mode into fuzzy based PID tuning.***

***Keywords:*** ***DC-DC converter, Fuzzy control, PID control, Energy conversion, PWM.***

## I. INTRODUCTION

Currently, energy issue has been emerging in the world because of limited fossil fuel and environmental problem. Herein, renewable energy and energy conversion technologies have been attracting from developer and policy maker. As DC-DC conversion technology is one of energy conversion, its operation principle is so simple and it has a long history in power electronic area.

However, its conversion efficiency is quite different depends on control method and algorithm. Solar energy or winds energy are important as renewable energy source for electricity generation especially in countries where the energy source is relatively limited.

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Regarding the development of DC power supply systems, DC/DC converters must meet the requirements of consumers or users, and a randomly energy conversions rate always should be operated under steady state condition at dynamically changing operating environment. Additionally, because a distributed power supply system provided by DC-DC conversion often contains multiple power sources, its control method can give on influence on the efficiency and conversion ratio. For this effective control of DC-DC converter, in the last three decades, many have been using Pulse Width Modulation (PWM) DC- DC converters or engineers have been doing a very strong emphasis owing to their various features and their broad applicability. Basically, the DC-DC converters are evolved to spread to almost every sector including transport, space and avionics, telecommunication, medicine and renewable energy. This is mainly thanks to new power semiconductor devices, new circuit structures and modern control techniques. Various DC-DC converters topologies including modeling have been suggested in many ways and categorized according to their power conversion applications. DC-DC buck, booster, regulator, and etc. is a fundamental converter in power electronics that can efficiently steps up the input voltage. It is showing increasing popularity in power conversion applications due to its simplicity, high boost ability and flexibility. It means that control system is more important in power conversion areas herein we should have a motivation to study. This paper suggests fuzzy based PID tuning method by introducing optimal switching time and mode of PWM. The results show the satisfactory response in conversion level.

## II. REVIEW ON RESEARCH LITERATURE

This paper [1] studies Full-Bridge DC/DC converter which is controlled by a new analog control and deals with design and analyzation. The key purpose of this paper is to ensure a smooth switching of the transistors, which makes it possible to reduce the losses of power, and consequently increases the efficiency of the overall system. Ref. [2] shows the electrical schematic of a DC-DC TLBC. The DC-DC converters present a nonlinear dynamic behavior, which increases their modeling and control complexity. His paper proposes a novel design procedure of proportional- derivative (PD)-like fuzzy logic controller (FLC) for dc–dc converters.

Ref. [3] illustrates neural network based converter control but it is over duty of our paper because of focusing on fuzzy based control. B. Y. Li [4] researches bidirectional transmission of energy by rational hardware design of a bidirectional DC/DC converter and improving the reliability of the DC micro grid energy storage system.

This paper explains model of DC/DC converter and uses PID controller for power control. Ref. [5] proposed the way of reducing of disturbance of the DC/DC converter through decoupling of dynamic behavior between the voltage loop and the current loop to become independent processes. They use PID controller for decoupled model in this paper.

This paper introduces an adaptive fuzzy PI controller (AFPIC) for DC-DC converter as one part, which can be easily energy conversion systems, of a flexible AC transmission system (FACTS) [6].

This paper [7] presents control strategy by fuzzy logic for achieving maximum benefits in 3phase 4wire distribution systems. The inverter is also controlled to perform as a multifunction device by incorporating active power filter functionality.

This paper [8] illustrates five-level inverter as a shunt active power filter to compensate reactive power and suppresses harmonics drawn from a diode rectifier. They employed self tuning filter and fuzzy logic controller to control the harmonic current extraction in inverter DC voltage. The proposed scheme is validated by computer simulation using MATLAB Fuzzy Logic Toolbox.

Ref. [9] is review paper. They reviewed control method such as PID, fuzzy, and sliding mode at DC-DC converter.

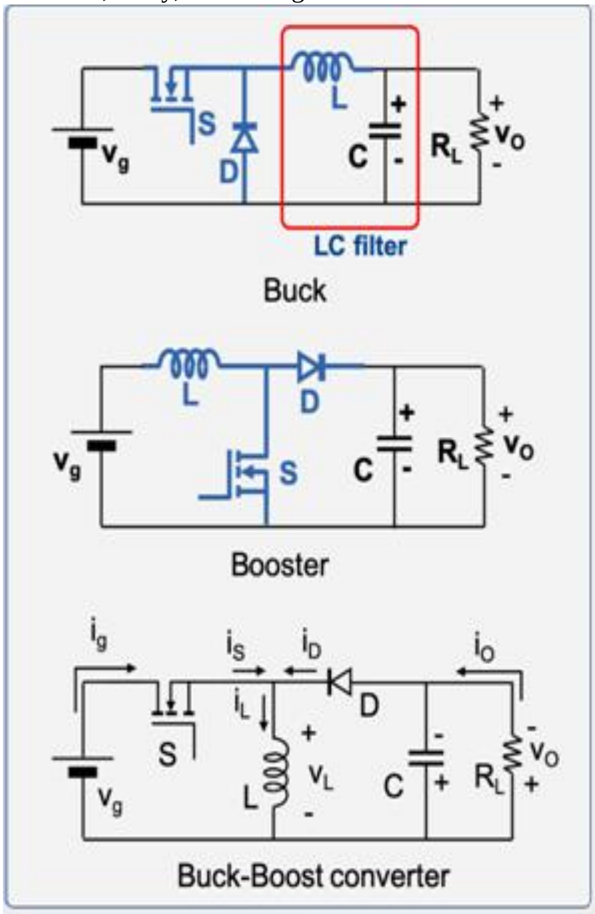



**Fig. 1. Structure of DC-DC power conversion.**

## III. CONTROL METHODOLOGY FOR DC-DC CONVERTER

### A. The model of DC-DC converter

Fig. 1 shows the overall block diagram of control system for DC-DC converter, Booster, and Buck-Booter. All power converter in these block diagrams need PWM to convert power and the performance of converting depends strongly on switching time and switching mode. Of course, relation switching time and switching mode can give on influence efficiency of conversion.

However, up to now, there is no control structure by using switching time, and switching mode or relation of these both because PI controller cannot use all input and cannot compute all input simultaneously.

### B. Optimal switching time of PWM Systems

To produce PWM, consider a switching circuit as shown in Fig. 2 and let us think for period (cycle time) of Ts seconds. Here, Ts is a constant and we count time in terms of numbers of cycles.

Suppose that at each cycle the switch starts at the H state and then transitions to the L state. Let the kth cycle consist of the time-interval (k, k + 1), k = 1, 2,..., and let dk denote the duty ratio of that cycle. Then, the switch is in the H state during the interval (k, k+dk), and it is in the L state during the rest of the cycle. When we consider the interval (k + dk, k + 1), optimal switching time can be defined as

$$J = \int_0^T \{L(x)t\}dt \tag{1}$$

By using this algorithm [12, 13], for the voltage source $v_s(t)$ = 1.8, the current source $i_o(t)$ = 1.0 simulation results illustrate the cycles 1- 30, 61-90. These values are quite important in this paper for width of fuzzy membership function.

### C. Optimal Mode-Scheduling for PWM

Optimal mode scheduling gives on the specification of PWM and the performance of DC-DC. Definition about optimal model scheduling of PWM is given as [13]:

$$J(\theta) = \frac{1}{2}\{v_c(t) - v_r(t)\}^2 \text{dt}. \tag{2}$$

With this definition, the single switching from L to H at the mid-point of the horizon interval is given as v(t)=0 for t ∈ [0, T/2] and v(t)=1 for t ∈ [ T/2, T]. This paper uses this optimal scheduling for the fuzzy membership function of PWM.

This paper also defines relation between optimal switching time of PWM systems and optimal mode-scheduling of PWM that can give on DC-DC conversion by using fuzzy relation and uses controller design.

Fig. 3 represents the shape of PWM defined by switching time and switching mode. This paper selects that the voltage source have the constant value vs(t) = 1.8, while the current source had the value io(t) = 1.0 during the cycles 1- 30 and 61-90 and io(t) = 2.0 during cycles 31-60, as shown in Figure 2. The prediction horizon was M = 2, the initial condition was x(0) = (0,0)⊤, and the parameters α and β in Algorithm 1 were set to α = β = 0.5 for studying switching mode.

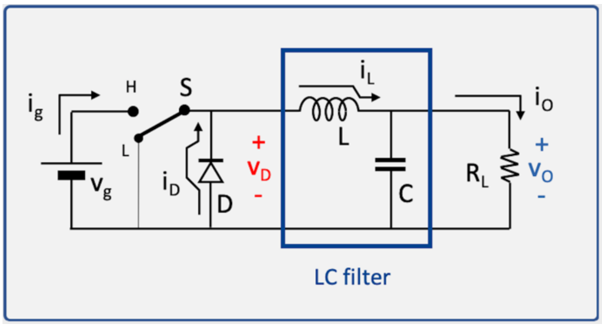



**Fig. 2. Sampling time of DC-DC converter.**

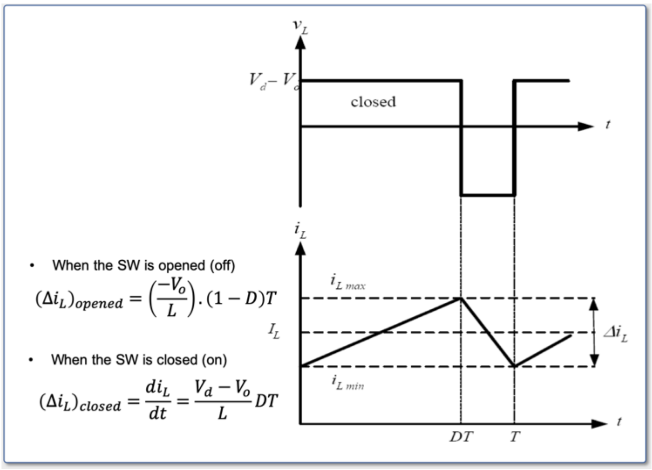



**Fig. 3. Switching mode for DC-DC converter.**

Fig. 4 shows the structure of output feedback loop controller of DC-DC converter and error amplifier have function to detect error between reference signal $V_{ref}$ and power out $V_{out}$, Modulator represents to generate PWM (Pule Width Modulation) for providing power converter DC-DC.

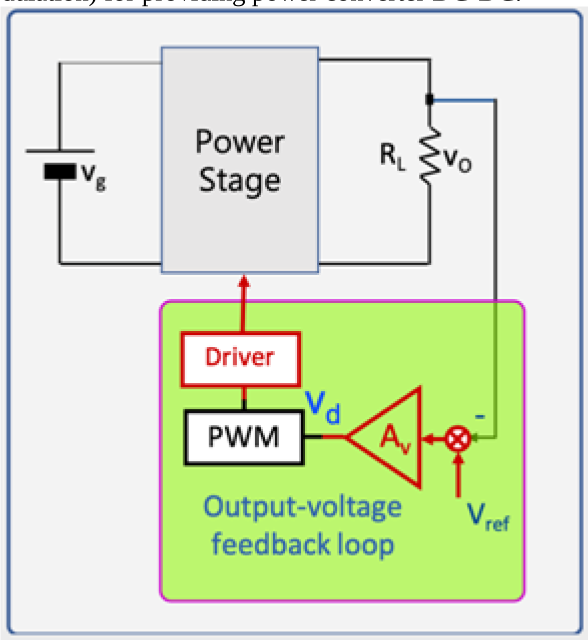



**Fig. 4. Output feedback loop control of DC-DC.**

Usually, designers use the fixed PWM form such as pulse time, pule duty time, switching time, switching mode, etc. Therefore, when load changes, the efficiency of DC-DC converter varies depends on a dynamically changing load. Especially, if load is big or situation of load changes, converting efficiency of DC-DC converter decrease seriously.

Reference [13] also concerns an alternative problem to the PWM and consider a given horizon of length T and the number of switching in the horizon is to be determined.

**D. The Structure of PID Control for DC-DC converter**

Fig. 5 shows the structure of PI for DC-DC converter in Ref [14, 15] depicts the generally PI control for DC-DC converter. The structure of the PID (proportional-integral-derivative controllers have been widely using owing to their simplicity and robustness in the industrial areas such as process control, motor drives, magnetic and optic memories, automotive, flight control, instrumentation, robot, and etc. In industrial applications, more than 90% of all control loops are suing the PID controller so far.

On the other, over the past 50 years, several methods for determining PID controller parameters have been developed for stable processes that are suitable for auto-tuning and adaptive control [16].

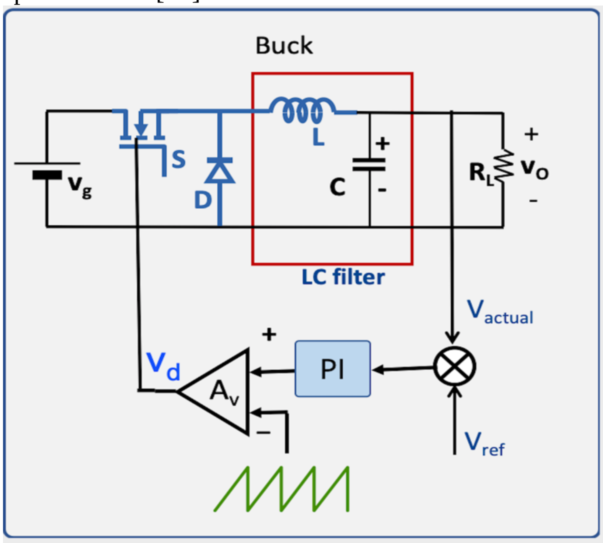



**Fig. 5. PI control loop of Converter.**

The tuning of these controllers for plants with over-damped step responses is well studied and many tuning formulas are given in the literature: the Ziegler–Nichols formula, the refined Ziegler–Nichols formula [3], the Cohen–Coon formula, the internal model control design formula, the integral absolute error optimum formula, the integral squared error optimum formula, the integral time-weighted square error optimum formula. However, they are normally solved by numerical methods or trial and error graphically using Bode plots. Such approaches are not very suitable for adaptive control [16-20]. However, there are not so many applications in DC-DC converter.

**E. The Structure of Fuzzy Tuning PID Controller for DC-DC Converter**

Fig. 6 shows the structure of fuzzy controller of this paper. Overall structure of fuzzy controller is similar like Fig. 5. However, the function and role of fuzzy controller is quite different from PI controller. When we design fuzzy, we introduce switching time and mode of PWM into membership function mode of fuzzy controller. That is, this paper set up fuzzy membership function with switching mode and time and use this membership to tune PID parameter. Consequently, switching time and mode of PWM give an influence on parameter tuning of PID controller.

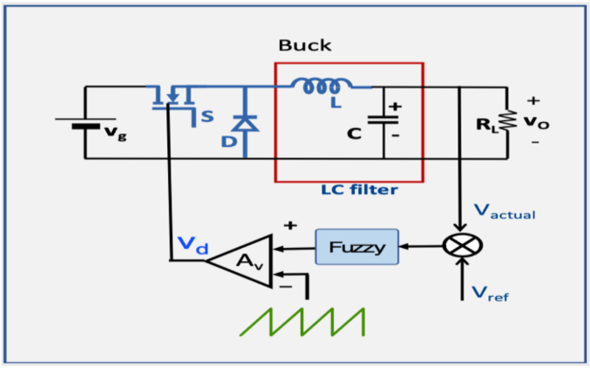



**Fig. 6. Switching time and mode of PWM introduced fuzzy control loop of converter.**

## IV. SIMULATION AND RESULTS

### A. The Structure of Simulink for Simulation

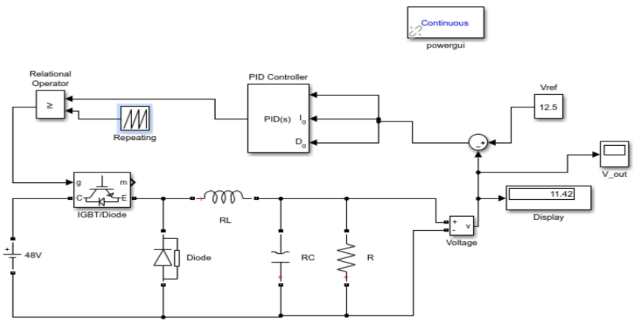
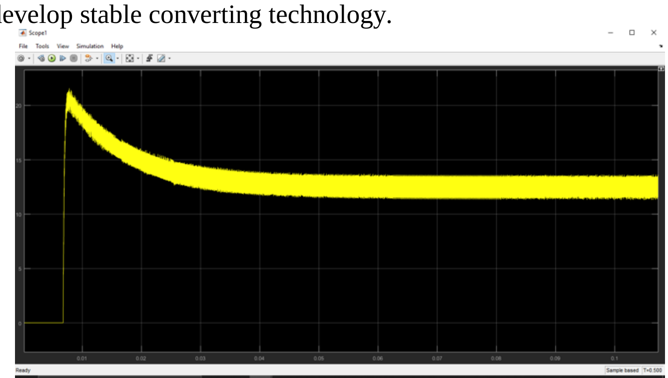
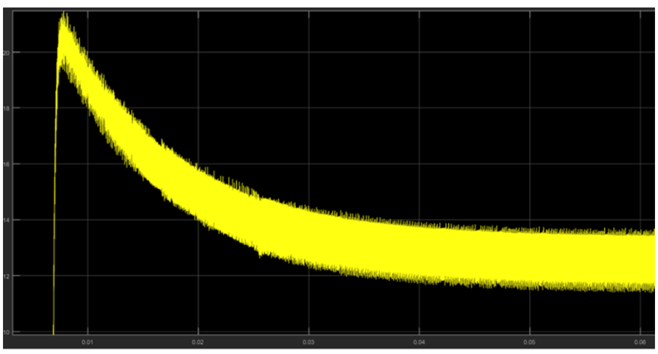



**Fig. 7. Simulink mode of PID control loop.**

Fig. 7 shows Simulink **mode** of PID control structure for DC-DC converter. Fig. 8 shows the output of DC-DC converter by PID controller. As Fig. 8(b) enlarge initial part, it has so much oscillation. That is, the output (voltage) of DC-DC converter by PID is unstable. This is limitation of DC-DC converting of PID. Herein, we strongly need to develop stable converting technology.



**(a) The output voltage by PID**



**(b) Enlarged output by PID**

**Fig. 8. Result of fuzzy tuning PID control for Converter.**

### B. The Characteristic of Fuzzy Controller

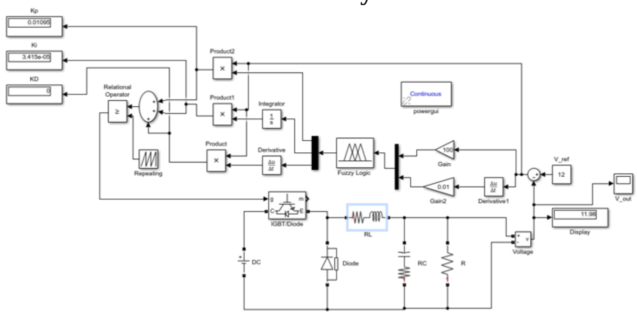



**Fig. 9. The structure of fuzzy tuning PID control.**

Fig. 9 illustrates the structure of PID control system tuned by fuzzy for DC-DC converter. Two fuzzy membership functions for tuning of PID controller are shown from Fig. 10 and Fig. 11.

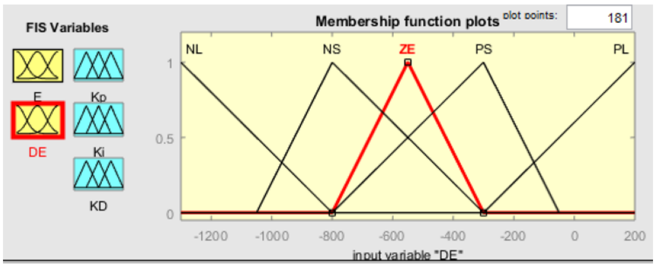



**Fig. 10. The change of error membership function for PID tuning.**

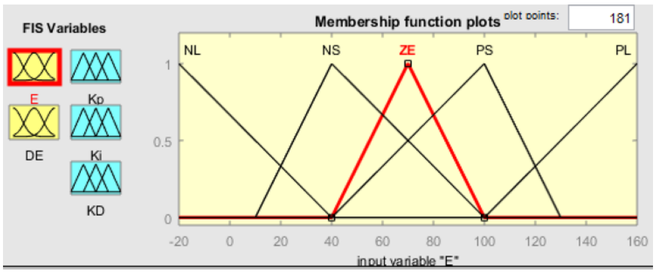



**Fig. 11. The error membership function for PID tuning.**

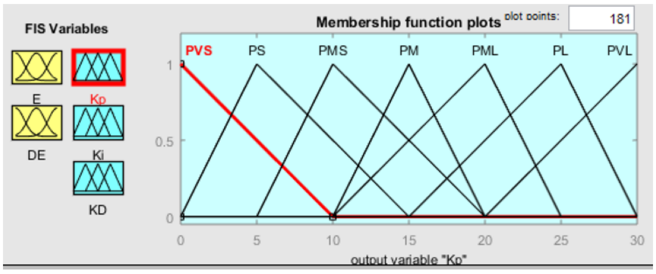



**Fig. 12. Membership function for Kp tuning.**

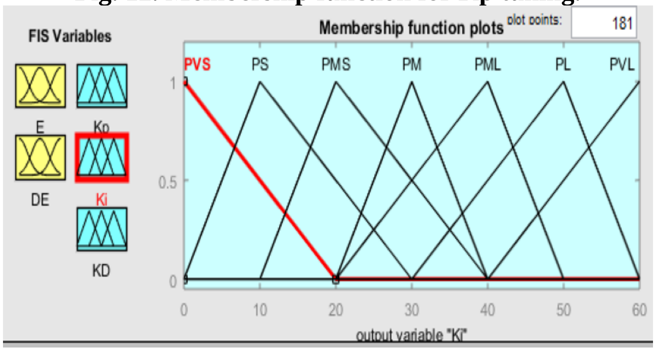



**Fig. 13. Membership function for Ki tuning.**

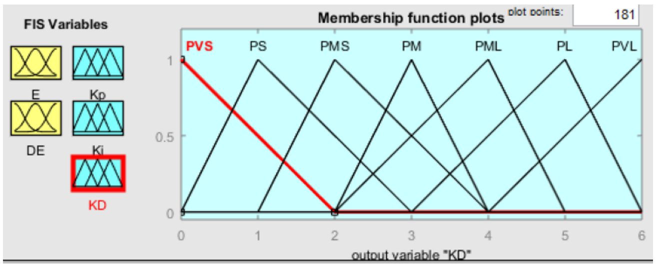



**Fig. 14. Membership function for Kd tuning.**

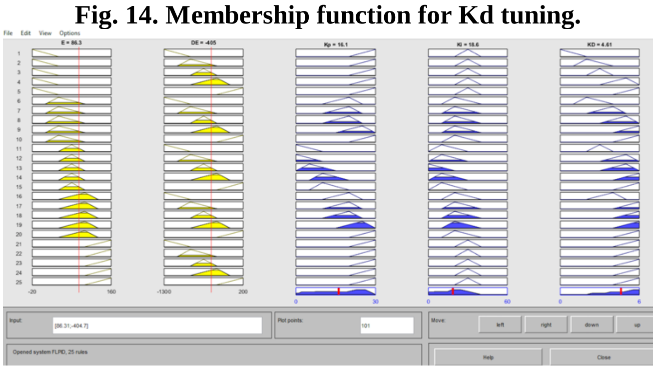


**Fig. 15. Defuzzification of tuning.**

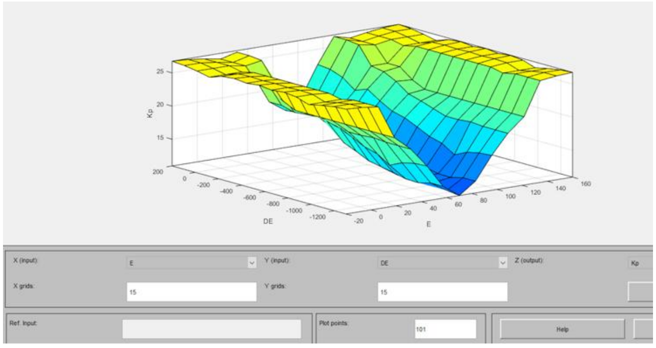


**Fig. 16. Fuzzy surface of input and output.**

Fig. 10 is the change of error membership for PID controller tuning and Fig. 11 illustrates the error membership function for PID tuning. Fig. 12 represents the membership function for $K_p$ gain of PID controller. Fig. 13 presents the membership function for $K_i$ tuning of PID controller. Fig. 14 shows the membership function for $K_d$ tof PID tuning. Fig. 15 is shape of the defuzzification of tuning results and Fig. 16 illustrates fuzzy surface of input and output. Table 1 represents parameter P, I, D tuned by fuzzy for DC-DC converter. D-value of Table 1 shows '0'. That is, it (D-function) is not necessary for optimal control in this DC-DC converter by tuning. Fig. 17 is graph of final voltage response by fuzzy based PID controller. Response is very reasonable.

**Table 1. P, I, D values tuned by fuzzy.**

| Item | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| P | 0.2863 | 0.2863 | 0.2863 | 0.2863 | 0.2863 | 1.3503 |
| I | 0.01126 | 0.04264 | 0.08193 | 0.1088 | 0.1148 | 7167.3 |
| D | 0 | 0 | 0 | 0 | 0 | 0 |

## V. CONCLUSION

This paper focuses on optimal energy control of DC-DC-converter by fuzzy based PID tuning. For that, this paper introduces wave form (switching time and switching mode of PWM) into mode of fuzzy membership function. That is, switching time and switching mode of PWM can give an influence on optimal control and the performance of DC-DC converter.

The efficiency of fuzzy controller in DC-DC converter have a good response as shown in Fig. 17.

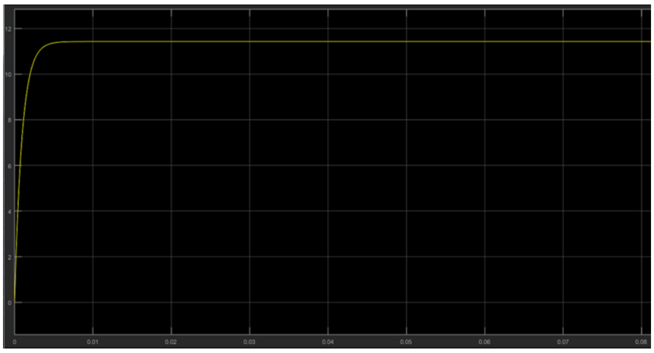


**Fig. 17. Final voltage response by fuzzy based PID controller.**

## REFERENCES


1. E. Baghaz, et. Rl, "Study and Design of a Full Bridge DC / DC Power Converter," Universal Journal of Electrical and Electronic Engineering, vol. 6, No. 2, pp. 31-45, 2019.
2. Neethu Raj. R "Fuzzy Controllers for Boost DC-DC Converters," IOSR Journal of Electronics and Communication Engineering (IOSR-JECE) e-ISSN: 2278-2834, p- ISSN: 2278-8735, pp. 12-19, 2016.
3. Ihab S. Mohamed, "A Neural-Network-Based Model Predictive Control of Three-Phase Inverter With an Output LC Filter,"
4. B. Y. Li, "Working principle analysis and control algorithm for bidirectional DC/DC converter," Journal of Power Technologies Vol. 97, No. 4, pp. 327–335, 2017.
5. Yimin Lu, "Inverse-System Decoupling Control of DC/DC Converters," Energies, 179, pp. 2-19, Dec. 2019.
6. Emre OZKOP, "An adaptive fuzzy PI controlled bus quantity enhancer for wave energy systems," Turk J Elec Eng & Comp Sci (2016) 24: 2454 – 2468, 2016.
7. K. GIRIDHAR, "Power Quality Improvement by Using Fuzzy Controlled Four Leg Inverter for Renewable Energy Sources," IRJET), Vol. 3, No. 7, pp. 1023-1029., 2016.
8. L. Zellouma, "Fuzzy logic controller of five levels active power filter," Energy Procedia, Vol. 74, pp. 1015 – 1025, 2015.
9. Sujata Verma, "Overview of control Techniques for DC-DC converters," Research Journal of Engineering Sciences, Vol. 2(8), pp. 18-21, 2013.
10. Hilmi ZENK, "Dynamic Performance Comparison of Cúk Converter with DC Motor Driving and Using PI, PID, Fuzzy Logic Types Controllers," Universal Journal of Electrical and Electronic Engineering, Vol. 2, No. 2, pp. 90-96, 2014.
11. S. Parthasarathy, "Comparative Analysis of Dual Input DC-DC Converters for Hybrid Power System," IJITEE, Vol 8, No. 8S, pp. 586-592, June 2019.
12. S. Alme´r, S., Optimal Sampled Data Control of PWM Systems Using Piecewise Affine Approximations," 49th IEEE Conference on Decision and Control December 15-17, 2010.
13. Luis Rodrigues, "Piecewise-affine state feedback for piecewise-affine slab systems using convex optimization," Systems & Control Letters 54, pp. 835 – 853, 2005.
14. Hartono Darmawaskita, "DC/DC Converter Controller Using a PICmicro® Microcontroller, technical report, 2002.
15. P. Saravanan, "Comparative analysis of PID and Fuzzy Based Control of SEPIC Fed Multilevel Inverter Scheme with Reduced Torque Ripple Content," IJEAT, Vol. 8, No. 3S, pp. 737-740, Feb. 2019.
16. ACPA, Special Issue on Advance in PID control, Asian Journal of Control, Vol. 4, No. 4, 2002.
17. K. J. Astrom, T. Hagglund, C. C. Hang, and W. K. Ho, "Automatic Tuning and Adaptation for PID Controllers-A Survey," IFAC J. Control Eng. Practice, Vol.1, no.4, pp.699-714, 1993.

18. K. J. Astrom, T. Hagglund, PID Controllers: Theory, Design, and Tuning. Research Triangle Park, NC: ISA, 1995.

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