A Comparative Study of PI Controller and Fuzzy Logic Technique for DC/DC Boost Converter in Photovoltaic System.

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***Abstract*- This work introduces an approach to design the controller for the closed loop system for DC/DC boost converter. This system is controlled by using PI controller and Fuzzy logic technique. The converter is design to step up the solar panel voltage to a stable 12V output. The output of the converter is measured and the values are sent to the controller to produce pulse width modulation (PWM) signal. The PWM signal is used to control the duty cycle of the converter. These simulations was developed using the Simulink tool box in Matlab software. Simulation and results of both controllers are compared to demonstrate the advantages and disadvantages between PI controller and Fuzzy logic technique.**

***Index term*-Dc/Dc Boost Converter; Fuzzy logic controller (FLC); PI controller; Storage; MATLAB Simulation**

I. INTRODUCTION

Nowadays, the switching power supply technologies are step forward into the next higher level in today's high-tech world. Almost all of the newer equipment in the DC/ DC converter is to change the DC energy from one voltage level to another by performing the conversion with the high efficiency. As a solution, controller is added to the system to achieve the goal for regulating the output of the DC/DC boost converter. In this paper, the closed loop system is controlled by using PI controller and Fuzzy logic technique. It can produce the accurate value, increase the rise and settling time characteristics and minimize the overshoot of the output voltage. Design the components especially for the inductor has been done to ensure the converter operate in continuous conduction mode (CCM). Besides, the values of the other parameters also influence the maximum performance of the system. Typical application of this boost converter is to provide DC power supply for standalone system without the storage element such as battery. The main reason of the absence of the storage elements is because of their size and high maintenance fees. Furthermore, the converter unit can be attached to the solar panel as a single product [1]

II. BOOST CONVERTER ANALYSIS

A simple DC/DC boost converter consists of an inductor, a switch (IGBT), a diode, a capacitor and a resistor (load) as shown in fig 1. The switch can operate into two states. State 1 begins when the switch is turned ON at t=Ton as shown in fig 2. The input current will flows through the inductor and switch. During this state, the energy is stored in the inductor. State 2 begins when the switch is turned OFF at t=Toff. The current that was flowing through the switch would now flow through the inductor, diode, capacitor and resistor as shown in fig 3. The inductor current falls until the switch is turned ON again in the next cycle. Energy stored in the inductor is then transferred to the load. Therefore, the output voltage will become greater than the input voltage [9].

$$V_0 = Vin\frac{1}{1-\delta} \qquad (1)$$

Where $V_0$is the output voltage, δ is the duty cycle and Vin is input voltage.

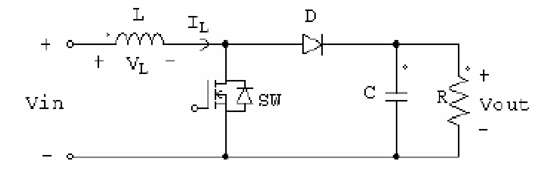

Figure 1: Circuit diagram of boost converter

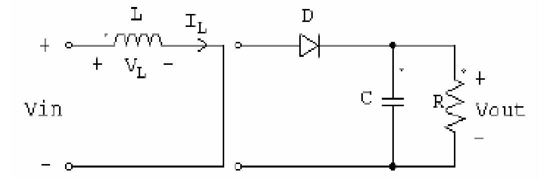

Figure 2: State 1-Circuit diagram of boost converter during Ton

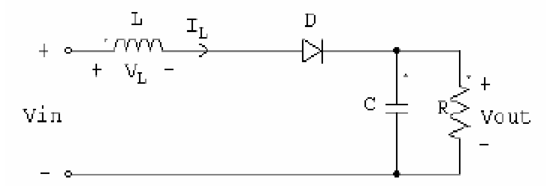

Figure 3: State 2-Circuit diagram of boost converter during Toff

$L_{critical}$ is determining in order to operate the converter in continuous conduction mode (CCM). The inductor is calculate to make surethe inductor current I_L flows continuously an never falls to zero as shown in fig 4 [9].

$$Lcrit = \frac{Vo(1-\delta)^2\delta T}{2Idc} \qquad (2)$$

Where $L_{critical}$ is the minimum inductance, V_0 is the output voltage, δ is the duty cycle and T is the time for 1 cycle.

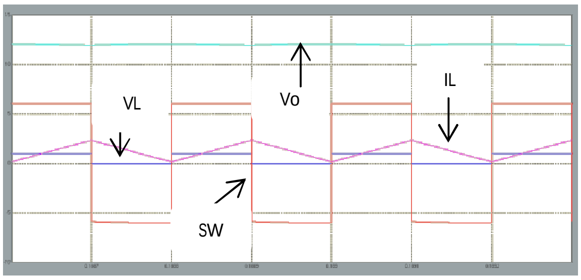

Figure 4: Waveforms for boost converter operating under CCM

The desired output voltage ripple can be determined by C_{min}. The capacitance is calculated to make sure the percentage of the voltage ripple within 1%-2% from the output voltage.

$$\Delta V = \frac{\delta T V o}{RC} \qquad (3)$$

Where ΔV_0 is the output voltage ripple, δ is the duty cycle and T is the time for 1 cycle, V_0 is the output voltage. The parameters of the boost converter are show in the table 1.

TABLE 1
PARAMETER VALUES

Components	Parameters(FLC)	Parameters(PI)
Input voltage	6V	6V
Output voltage	12V	12V
Inductor	0.275mH	0.275mH
Capacitor	500uF	500uF
Resister	20Ω	20Ω
Switching	IGBT	IGBT
Proportional gain, K_p	Nil	4.55e-3
Integral gain, K_i	Nil	5.114
Solar panel, Vmax	12V	12V
Solar panel, Imax	40mA	40mA

III. PI CONTROLLER ANALYSIS

PI controller is one of the control theories that have been used in closed-loop industrial processes for the last few decades [6], [2]. The PI controller consists of two gains that are proportional gain, K_p and integral gain, K_i as shown in fig 5. A proportional gain, K_p reduced the error but not eliminated it and an integral gain, K_i will have the effect of eliminating the steady-state error but it may worsen the transient respond [8]. Pi controller is based on a linear model, but the response is very poor when there is a large signal disturbance. On the other hand, a PI controller hardy satisfies the high performance criterion with respect to the insensitivity and disturbance [2], [6].

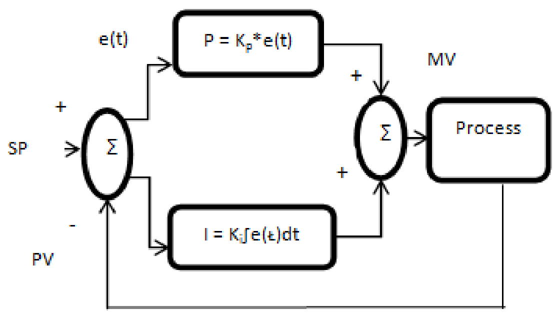

Figure 5: Closed-loop PI controller

The Ziegler-Nichols tuning method is a heuristic method of tuning a PI controller which is to choose the best values of proportional gain, K_p and integral gain, K_i. It is perform by setting the values of K_p to 0.1 and k_i to zero at initial condition and run the simulation. The input waveform of PI controller is observed to calculate the values of ultimate gain, K_u and oscillation period, T_u. The values of K_u and T_u are used to determine the value k_p and k_i as shown in table 2 and fig 6 [10], [11]. The PI controller simulation circuit is shown in fig 7.

TABLE 2
ZIEGLER-NICHOLS FORMULA

Type controller	Proportional gain, k_p	Integral gain, k_i
P	Ku/2	-
PI	Ku/(2.2 x 2)	1.2Kp/Tu

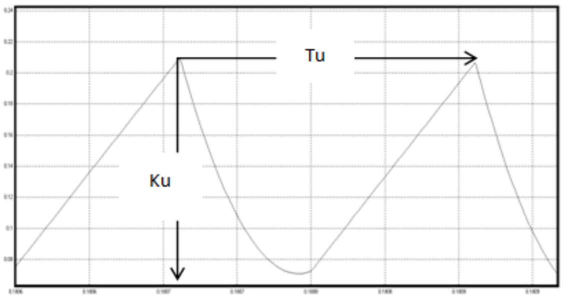

Figure 6: Ziegler-Nichols tuning

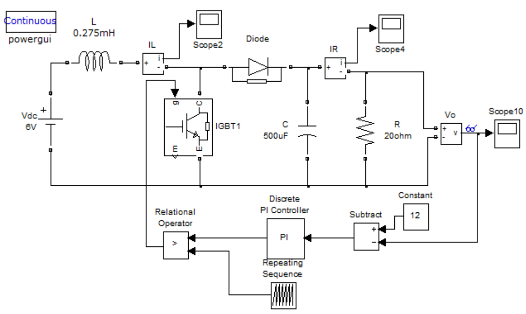

Figure 7: PI controller simulation circuit

VI. FUZZY LOGIC CONTROLLER ANALYSIS

Fuzzy logic controller (FLC), which was introduced by L.A.Zadeh is a design philosophy that deviates from all previous methods which were developed by the expertise in the design of controllers [12]. Fuzzy set theory that obtained from the fuzzy logic control show the transition between membership and nonmembership can be progressively. Therefore, boundaries of fuzzy sets can be vague and ambiguous; hence, it is useful for approximate system. The FLC is divided into four models: fuzzifier, rule evaluator, defuzzifier, rulebase and database as shown in fig 8 [2].

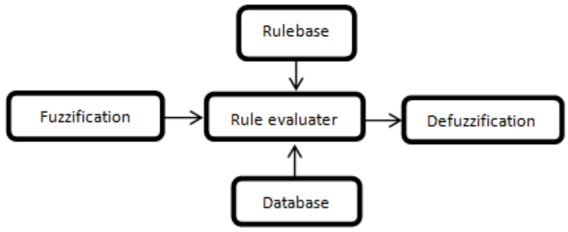

Figure 8: Closed-loop Fuzzy Logic Controller

A. *Fuzzier*

In FLC, the non-numeric linguistic variables are often used to facilitate the expression of rules and facts instead of numerical variables. In mathematics variables, the measured quantities are real numbers (crisp). The converting process from numerical variables (real number) into non-numeric linguistic variables (fuzzy number) is called fuzzification [2]. The triangular membership functionis a graphical representation of the magnitude of participationof each input and output. Fig 9 show the triangular membership function used in fuzzification. For a given numerical variables input, fuzzifier finds the degree of membership in every linguistic variable. [2].

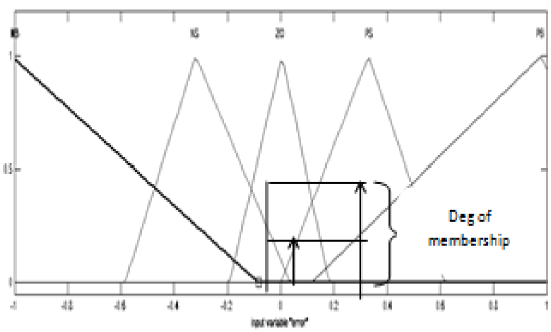

Figure 9: Closed-loop Fuzzy logic controller

B. *Rule Evaluator*

In FLC, the equivalent term is rules and they are linguistic in nature, different with the conventional controllers which the control gains are combination of numerical values. A typical rule can be written as follows

If E is Ai and CE is Bi then output is Ci(4)

Where Ai, Bi, Ci is the labels of linguistic variables of Error (E), Change of Error (CE) and output respectively. E, CE and output represents degree of membership [2].

C. Database and Rulebase

The database and Rulebase is the temporarily storage elements that stores the data when the program is running. The Database stores the definition of the membership function that required by fuzzifier and defuzzifier. Besides, the Rulebase stores the non-numeric linguistic variables (fuzzy number) for the Rule evaluator to make decisions as show in table 3.

TABLE 3
RULEBASE

e / Δe	NB	NS	ZO	PS	PB	NB
NB	NB	NS	ZO	PS	PB	NB
NS	NS	ZO	PS	PB	PS	NS
ZO	ZO	PS	PB	PS	ZO	ZO
PS	PS	PB	PS	ZO	NS	PS
PB	PB	PS	ZO	NS	NB	PB

D. Defuzzification

A defuzzyfication interface produces a nonfuzzy control action from an inferred fuzzy control action. It is a reverse process of fuzzification [2]. The Fuzzy logic controller simulation circuit is shown in fig 10.

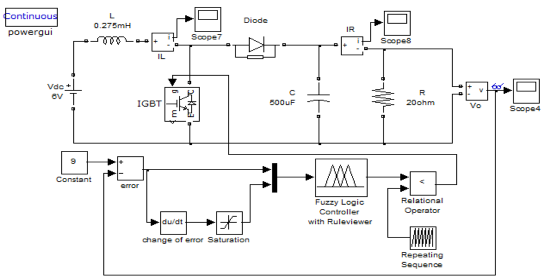

Figure 10: FLC controller simulation circuit

IV. RESULTS AND DISCUSSION

By using MATLAB simulink, the simulation results for proportional integral (PI) controller and Fuzzy logic controller (FLC) has been obtained. The simulation results include:

1) References Voltage (Vref)
2) Percentage of deviation voltage (%Vd)
3) Percentage of overshoot (%OS)
4) Rise time (Tr)
5) Settling time (Ts)

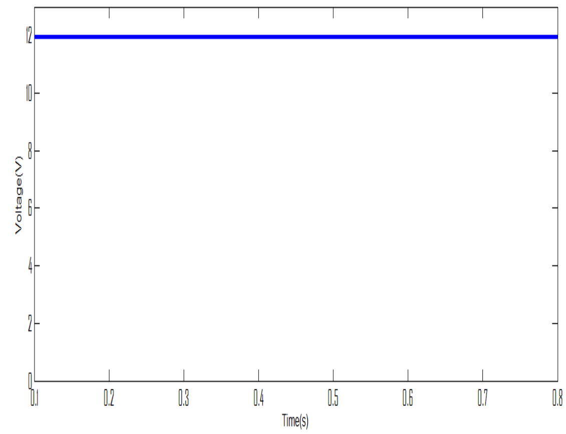

Figure 11: Output voltage of open-loop circuit

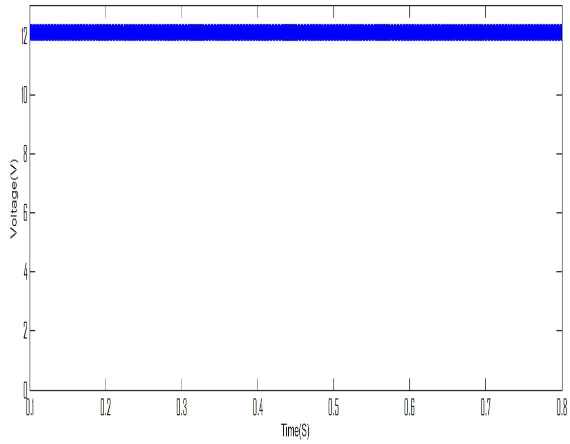

Figure 12: Output voltage of FLC

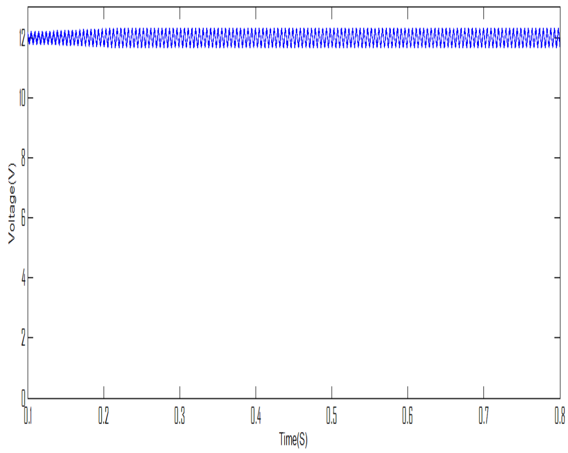

Figure 13: Output voltage of PI controller

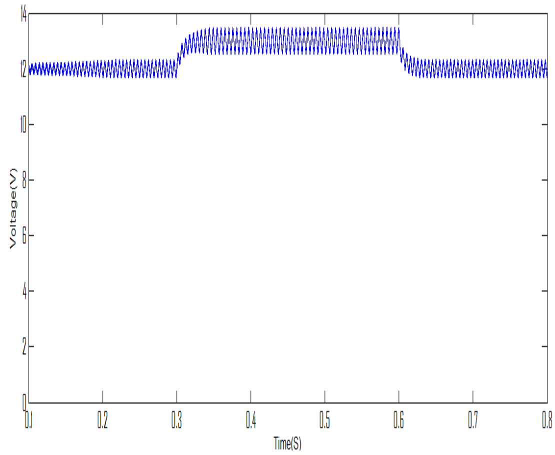

Figure 14: Effect of output voltage of PI controller
with adjusted Vref (12V-13V-12V)

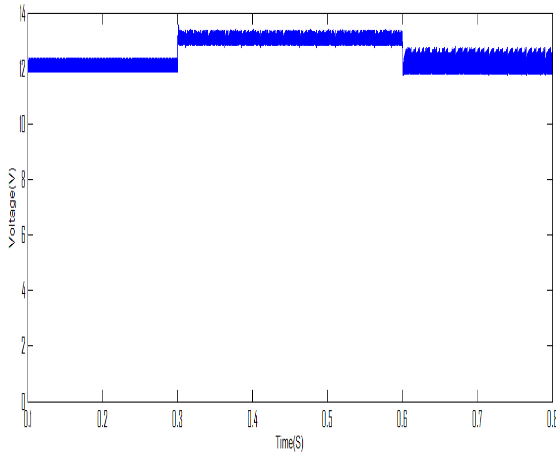

Figure 15: Effect of output voltage of FLC
with adjusted Vref (12V-13V-12V)

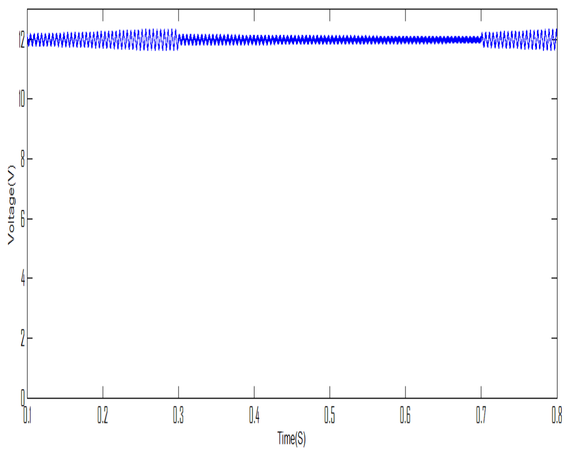

Figure 16: Effect of output voltage of PI controller
due to sudden injected the parallel resistor (I Load increase 20%))

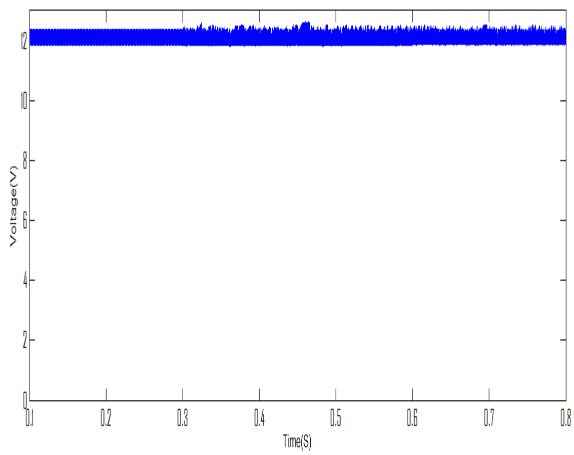

Figure 17: Effect of output voltage of FLC
due to sudden injected the parallel resistor (I Load increase 20%))

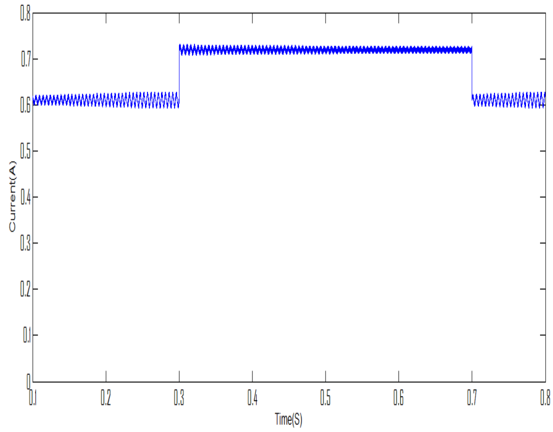

Figure 18: Effect of output current of PI controller
due to sudden injected the parallel resistor (I Load increase 20%)

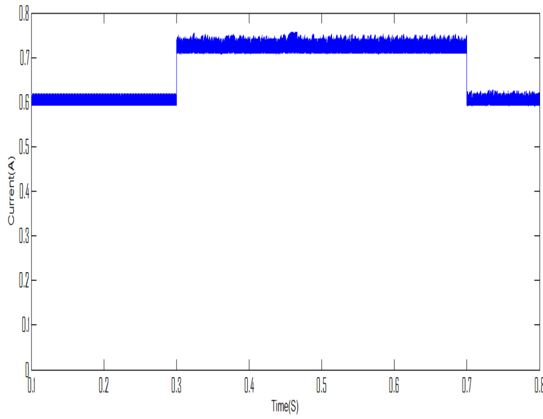

Figure 19: Effect of output current of FLC
due to sudden injected the parallel resistor (I Load increase 20%))

Based on the waveform obtained in fig 12 and fig 13, the ripple output voltage of FLC is small compared with PI controller. The observation and comparison can be guide with the output voltage waveform that obtained from the open-loop circuit in fig 11 where the PWM signal are generated by using function generator. Even the value of the $L_{critical}$ and C_{min} is calculated just to make sure that the converter is operated in continuous conduction mode, the level of efficiency each controller determine which one is the highest.

Fig14 and fig 15 shows the output voltage when the pulse switch of the reference voltage was applied. The reference voltage is varied from 12V from 0.0s-0.3s and then step up to 13V from 0.3s-0.6s which is 10% from the 12V of the output voltage and lastly it is step down to 12V from 0.6s-0.8s. From the observation, the output voltage waveforms between PI controller and FLC have the same level of effectiveness but in term of efficiency and sharpness in controlled the sudden changing; FLC is more than Pi controller.

Fig 18 and fig 19 shows the injected pulse switch of the parallel resistor R2 (I Load increase 20%) from 0.3s-0.6s to observe the efficiency of controllability of both controllers. From the observation, the efficiency of controllability of the PI controller is more efficient compared to the FLC. Even FLC has lower efficiency of controllability compared with PI controller, but it is already controlled the output waveform back to its line.

Fig 18 and fig 19 shows the load current waveform due to sudden injected the parallel resistor. The ripple output current waveform in FLC has small compared with PI controller.

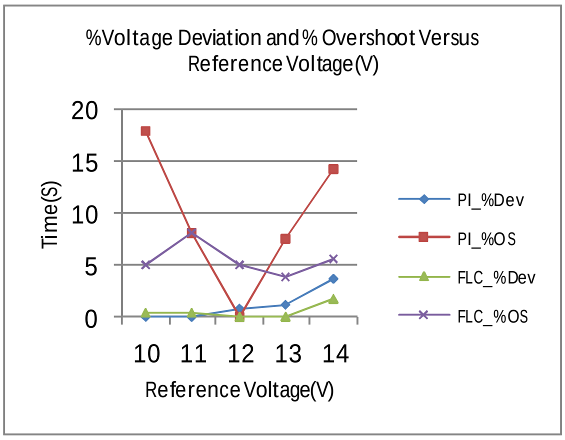

Figure 20: Percentage voltage deviation for PI and FLC

The plotted graph at fig 20 had shown the comparison between Pi controller and FLC in term of percentage of the deviation voltage and overshoot. The highest percentage of deviation voltage for PI controller is 3.71% when the reference voltage is set to 14V meanwhile for FLC, the highest percentage of overshoot is 1.86% at 14V of reference voltage. On the other hand, the highest percentage of overshoot for PI controller is 18% when the reference voltage is set to 10V meanwhile for FLC is 8.18% at 11V of reference voltage. Since the both controller currently achieve the desired output voltage after the adjusted of the reference voltage is applied, the graph of percentage deviation voltage overshoot for FLC are more stable and less fluctuate compared with PI controller.

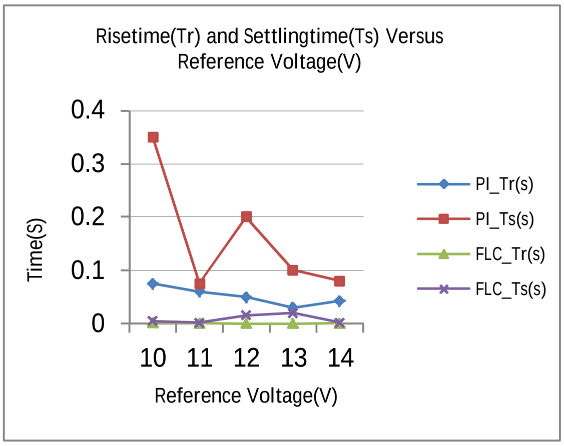

Figure 21: Rise time (Tr) and settling time (Ts) for PI and FLC

The plotted graph at fig.21 had shown the comparison of the Rise time (Tr) and Settling time (Ts) between PI controller and FLC.From the fig 21, the average value of the rise time(Tr) and settling time (Ts) for PI controller is below than 0.075s and 0.008s, while, for the FLC the average value of rise time (Tr) and settling time (Ts) is below than is 0.001s and 0.02s. It shows that the rise time and settling time for PI controller is slower than the FLC. Based on two type of time, Pi controller are currently not stable and much slower than the FLC. The fig 21 observed that, the rise time (Tr) and settling time (Ts) for FLC is more stable and less fluctuates compared with PI controller.

VI. CONCLUSION

In conclusion, Fuzzy Logic Controller (FLC) has been proved more accurate in term of calculating error whether at rise time (tr), settling time (ts), percentage overshoot and voltage deviation. FLC presented fast response at the rise time with maximum accuracy and minimize the percentage overshoot voltage as lower as possible. Furthermore, the settling time for the FLC to gain the constant desired output voltage is rapid and less fluctuates with the small voltage deviation. Besides, the FLC has been found more effective and efficient controller when there is parallel resistor were sudden injected to the load. Other than that, the FLC also can control the sudden change in reference voltage at higher efficiency and give the accurate desired output voltage.

On the other hand, the response of the proportion integral (PI) controller is slower at the rise time because of the undershoot voltage and large output voltage ripple. The settling time of the PI controller to achieve the steady state of the desired output voltage is sluggish and fluctuated. In term of control the sudden injected of the parallel resistor and change in reference voltage, Pi controller is at the same level and condition with FLC in effectiveness and efficiency characteristic. Even the implementation of hardware on dc/dc boost converter with open-loop programming code using peripheral interface controller has been developed, for the further work can be performed with the closed-loop programming code to prove that hardware application gives same performance as the software simulation

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