# Intelligent Performance Analysis of Accelerated Fuzzy Controlled DC-DC Boost Converter

**Dr. R. Sagayaraj, Professor& Head-Department of Electrical & Electronics Engineering, AVS Engineering College, Ammapet, Salem, Tamilnadu, India. rsrajeee@yahoo.co.in**

**Dr. A. Nazar Ali, Associate Professor-EEE, Rajalakshmi Engineering College, Chennai, India. nazarali@ieee.org**

**Abstract Power Quality is the lifeblood which is anticipated by almost all electrical consumers; however, with the tremendous development in power electronics, problems of voltage quality and their solutions are the hotspot issues. Nowadays dc loads are increasing randomly due to industrial growth hence; it is necessary to maintain the quality of voltage in the perspective of stability and ripples. DC-DC boost converter introduced between dc source and load aids the stability crisis to a greater extent, however controlling the parameters of the boost converter decides the stability and voltage ripples. Conventional PI controller reduces voltage ripple, but perhaps it is poor in maintaining a constant voltage. In this paper, artificial intelligent Accelerated fuzzy PI controller is proposed to control the dc-dc boost converter, which paves the way to reduce the ripple content and maintains power quality, constant voltage irrespective of the load connected across the output terminals. The performance of the proposed intelligent controlled strategy is compared with a conventional PI controller and a trade-off is obtained. The entire system is analyzed using Matlab/Simulink simulation software.**

***Keywords — Accelerated fuzzy PI controller (AFPIC), Boost converter, DC-DC Converter, Fuzzy Logic Controller (FLC), PI Controller, Voltage Stability.***

## I. INTRODUCTION

Controlling switched power converters is a challenging research opportunity in control engineering. Although a typical dc-dc converter circuit requires few components and, from a theoretical point of view, it is simplistic to operate, all dc-dc converters which require control circuitry in order to account for load variations, component tolerances, system aging and input source voltage variations.

The controllers used in practical implementations are frequently of analog nature and have a PID compensator structure, with a sub optimal design for specifications. Hence, it is indispensable to design advanced controllers with the latest version in digital signal processors (DSP) [1], which can now be implemented in practice. From a control-engineering point of view, dc-dc converters are a traditional benchmark for testing (advanced) non-linear controllers. However, apart from their non-linear characteristics, dc-dc converters pose another interesting feature that, they have unstable zero dynamics -”non-minimum phase” systems.

However, inspite of these difficulties, a number of non-linear controllers have been reported in literature, such as: sliding mode control strategies [2], nonlinear PI controllers based on the method of extended linearization [3], and a predictive controller [4]-[5], using the in-house EPSAC algorithm [6]. The results of an experimental comparison of five control algorithms on a boost converter are presented in [7], linear averaged controller, linearizing feedback controller, passivity-based controller, sliding mode controller, sliding mode plus passivity-based controller.

A comparative analysis between three control methods using the small signals model for a Buck converter [8] reveals that the efficiency and robustness of fuzzy logic control compared to a classical proportional integral (PI) and sliding mode controllers are optimum for dc-dc converters. In the same area, [9] presented a universal fuzzy logic controller, which, unlike the PI case, ensures good performances regardless of the operating point variations. In [10] the authors used a conventional PID controller with a fuzzy logic based gain controller for dc-dc converter regulation. The PID controller parameters [15]are deduced from the approximated linear model of the dc-dc converter. In order to compensate for the neglected non- linear components and to improve the overall performances of the controller, the PID controller output gain is tuned using a fuzzy logic system. These works are generally based on a simplified small signal model, which considers the switches as ideal and neglects the equivalent series resistors across

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the inductor, capacitor and considering that in all operating point, the converter output voltage increases by increasing the duty cycle and vice versa. However, the system losses analysis [11,14] shows that the converter efficiency tends to zero when the steady-state value of duty cycle is approaching nearly one.

In this paper accelerated fuzzy PI controller is proposed to control the boost converter. To analyze the performance of stability a variable load is presented in this paper.

## II. ROLE OF BOOST CONVERTER

The dc-dc boost converter only needs four external linear components: An inductor, electronic switch, diode and output capacitor [11]. Hence the converter operates in two different modes depending on its energy storage capacity and the relative length of the switching period.

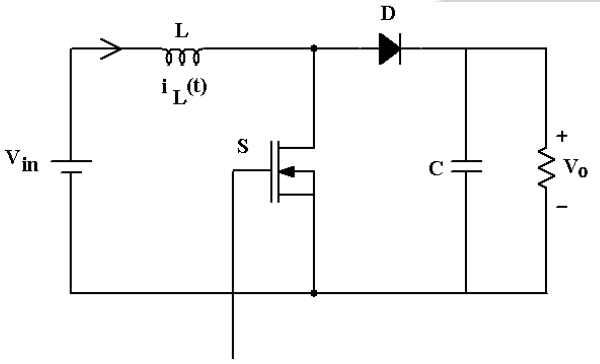


**Figure 1. Circuit Schematic of Step-Up dc-dc Converter**

Mode 1 : When IGBT is switched on at t = 0 and terminates at t = ton. The corresponding equivalent circuit of this model is shown in Fig. 2a. The inductor current iL(t) greater than zero and subsequently ramps up linearly. The inductor voltage is Vin.

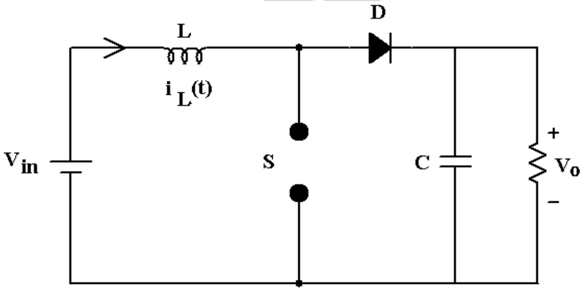


Figure 2.a. The Equivalent circuit Mode1

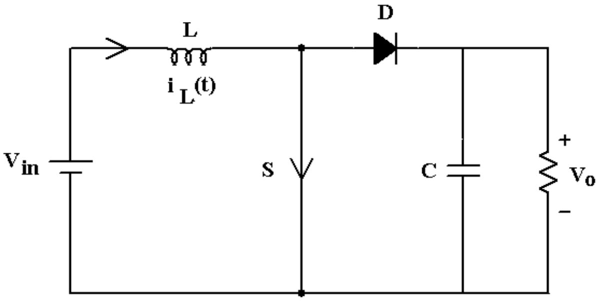


Figure 2.b. The Equivalent circuit Mode1

Mode 2 : When IGBT is switched off at t = $t_{on}$ and terminates at t = ts. The corresponding equivalent circuit of this model is shown in Fig. 2b. The inductor current decreases until the IGBT is turned on. The voltage across the inductor in this period is Vin-Vout. During the period of steady, state integral of the inductor voltage over one time period must be zero.

$$V_{in} * t_{on} + (V_{in} - V_o) * t_{off} = 0 \qquad (1)$$

Where,

$V_{in}$ : The input voltage, V.

$V_o$ : The average output voltage, V.

$t_{on}$ : The switching on of the IGBT's, sec

$t_{off}$ : The switching off of the IGBT's, sec

Dividing both sides by $T_s$ and rearranging items yield.

$$\frac{V_o}{V_{in}} = \frac{T_s}{t_{off}} = \frac{1}{1-D} \qquad (2)$$

Where,

$T_s$ : is the switching period, s.

D : is duty cycle.

## III. PERFORMANCE ANALYSIS OF BOOST CONVERTER

The fundamental circuit of the boost converter is shown in figure 3. Here, L is the inductor and R is the resistor which is considered as a load.

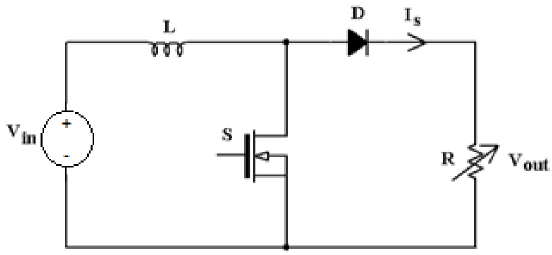


Figure 3. Basic Circuit of Boost Converter

When the switch is turned on, the magnitude of current across the inductor increases progressively. At the end of $T_{on}$ the current stored in the inductor is $I_s$. So,

$$V_{in} = L * \frac{dI_s}{dt} \qquad (3)$$

Using Laplace Transformation,

$$V_{in}(s) = L * s * I_s(s) \qquad (4)$$

$V_{out}$ can be given as

$$V_{out}(s) = I_s(s) * R \qquad (5)$$

From equation 4,

$$\frac{V_{out}(s)}{V_{in}(s)} = \frac{R}{L * s} \qquad (6)$$

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Equation 6 is the basic Laplace transformation equation of the boost converter.

The values of inductor, capacitor and breakdown voltage of diode are chosen by the following equations,

Min. Inductor size

$$L > D * V_{in} * \frac{(1-D)}{(freq * 2 * I_{out})} \quad (7)$$

Peak inductor current

$$I_{pk} = \frac{(V_{inmax} * D)}{(freq * L)} \quad (8)$$

Minimum capacitor

$$C > \frac{I_{out}}{V_{ripple} * freq} \quad (9)$$

Minimum Schottky diode

$$V_{breakdown} >= V_{outmax} \text{ and } I_{diode} >= I_{pk} \quad (10)$$

Where,

Freq -Switching frequency of the converter

$V_{ripple}$ - The maximum allowed ripple in the output voltage

$V_{inmax}$ -The maximum value of the input voltage

$V_{outmax}$ -The maximum value of the output voltage

$V_{breakdown}$ - The breakdown voltage of the diode

## IV. CONTROL STRATEGIES OF THE BOOST CONVERTER

The various control strategies of controlling the boost converter are discussed in this section. The traditional PI controller is still in vogue in most of the industries. However, in PI controller, the tedious task of tuning the controller constant is cumbersome and time-consuming. Hence an intelligent controller based tuning the controller constant is shown in this subsequent section.

### *A. PI Controller based boost converter*

The conventional PI controller offers the simplest method of control and is widely used in industries. Proportional plus Integral Controller increases the speed response. It produces a very low steady-state error. The general equation of the PI controller is

$$U(s) = K_p E(s) + \frac{K_i}{s} E(s) \quad (11)$$

Where $K_p$ is proportional gain, $K_i$ is the integral gain, E(s) is the controller input and U(s) is the controller output.

Ziegler Nichols' method of tuning is adopted to find the optimum value of $K_p$ and $K_i$ values. It produces high overshoot and long settling time.

### *B. Intelligent Controller based boost converter*

The controller decides the duty ratio of switching pulse. Since the output voltage of converter depends on the duty ratio. In this paper, three-phase source followed by rectifier feeds the boost converter. The required output voltage is set as the reference voltage and it is compared with the actual voltage feedback from the converter. It is taken as voltage error, which is considered as input to the controller. In this paper PI controller and Accelerated fuzzy PI controller are proposed to control the boost converter. The proposed system block diagram is shown in figure 4.

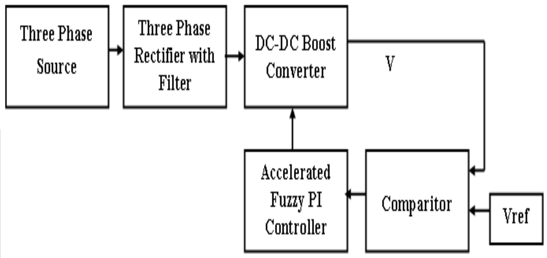


Figure 4. Block diagram of the proposed system

### *C. Accelerated Fuzzy PI controller based boost converter*

For improving the transient response of the system by modified improved version of Fuzzy PI controller. To understand the concept of Accelerated Fuzzy PI Controller, it is essential to know about the fuzzy PI controller.

The fuzzy PI controller is designed by replacing the conventional PI controller. The fuzzy inference of fuzzy PI controller is based on the fuzzy rule table set previously. Hence the algorithm of fuzzy inference reduces the complexity. The parameters of PI can be adjusted online, which can be changed through the inquiry of fuzzy control rule table saved in the digital computer. The calculation voltage of controller is very quick, which can satisfy the rapid need of a controlled object. The block diagram of the fuzzy PI controller is shown in Fig.5.

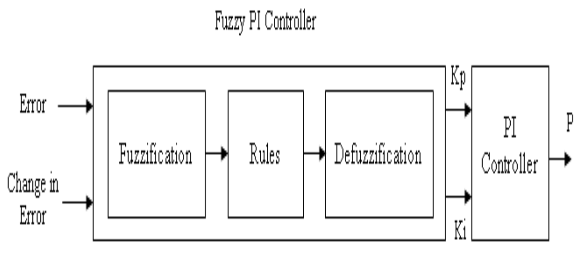


Figure 5. Fuzzy PI controller block diagram

The control algorithm of the traditional PI controller can be described as

$$u(k) = k_p e(k) + k_i \sum e(k)$$

Where $K_p$ is the proportional gain, $K_i$ is the integral gain and e (k) is the voltage error.

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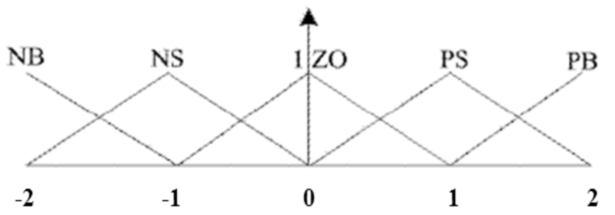


Figure 6.a. Fuzzy membership functions of E and EC

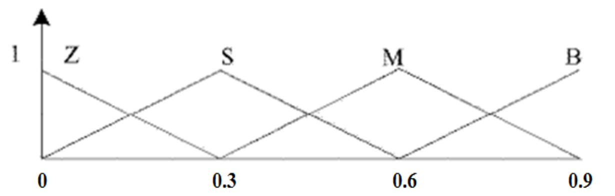


Figure 6.b: Fuzzy membership functions of $K_P$ and $K_I$

The principle of designing fuzzy rules is that the output of controller can make the system output response dynamic and static performances as optimal. The fuzzy rules are generalized as the table I and table II according to an expert experiment on the boost converter. The Mamdani inference method is used as the fuzzy inference mode. The inference can be written as "IF A AND B THEN C".

For example"

- If (E is NB) and (Ec is NB) then (Kp is B) (Ki is Z)
- If (E is NB) and (Ec is ZO) then (Kp is B) (Ki is Z)
- If (E is ZO) and (Ec is NB) then (Kp is M) (Ki is B)
- If (E is PB) and (Ec is NB) then (Kp is M )(Ki is Z)

$K_p$ and $K_i$ is written in the same as 25 fuzzy condition statements [13]. The output variable can be obtained by the MIN - MAX inference. The centroid method is adopted for defuzzification. The fuzzy PI controller uses only two inputs-voltage error (e) and rate of change of voltage error ($E_C$). But in this model, an additional input named 'accelerated rate of change of error (acc) is used to improve the transient response of the system [9].

TABLE I CONTROL RULES FOR $K_P$

| Kp | | Ec | | | | |
|---|---|---|---|---|---|---|
| | | NB | NS | ZO | PS | PB |
| E | NB | B | B | B | B | M |
| | NS | M | B | S | S | S |
| | ZO | M | B | Z | S | B |
| | PS | S | S | S | S | S |
| | PB | M | B | B | M | B |

TABLE II CONTROL RULES FOR $K_I$

| $K_i$ | | Ec | | | | |
|---|---|---|---|---|---|---|
| | | NB | NS | ZO | PS | PB |
| e | NB | B | B | B | B | M |
| | NS | M | B | S | S | S |
| | ZO | M | B | Z | S | B |
| | PS | S | S | S | S | S |
| | PB | M | B | B | M | B |

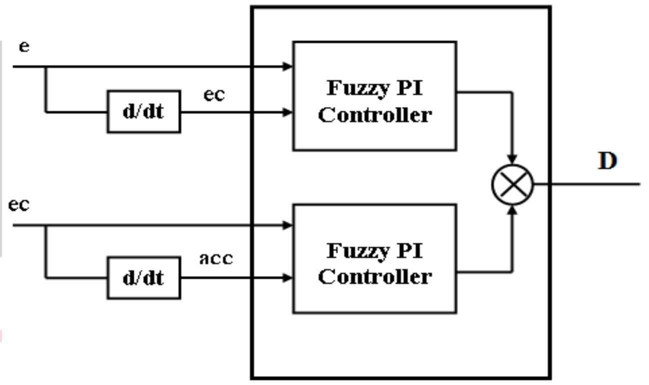


Figure 7. Accelerated Fuzzy PI controller block diagram

In each fuzzy controller, rules are the same as stated in table 1 and 2 respectively. Perhaps, only the inputs are varied.

## V. RESULTS AND DISCUSSION

In this paper, the DC-DC boost converter is fed by the rectifier and it is energized by a three-phase AC source. The entire system is simulated using Matlab/Simulink. The simulation model of the system is shown in figure 8.

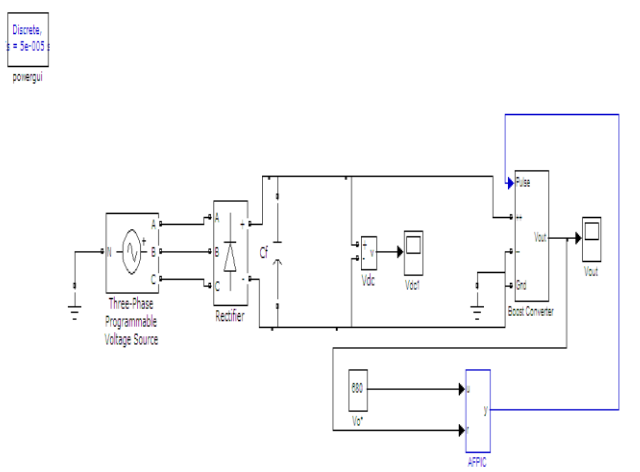


**Figure 8. Simulation model of AFPI controlled DC-DC boost converter**

To analyze the system performance, load is instantaneously increased. It causes a voltage drop in case of absence of controller. The application of controller in the aspect of voltage stability is analyzed.

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Fig. 9 shows the voltage oscillation without any controller which refers to the open loop response of boost converter. Initially, the system is analyzed using PI controller with variable load. Figure 10 shows the voltage output of PI controlled boost converter.

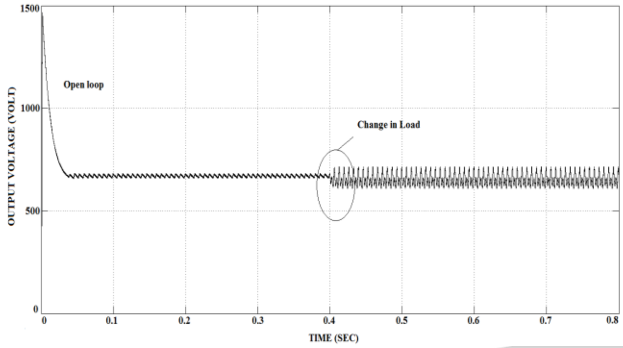


**Figure 9. Output voltage of open loop DC-DC boost converter with variable load**

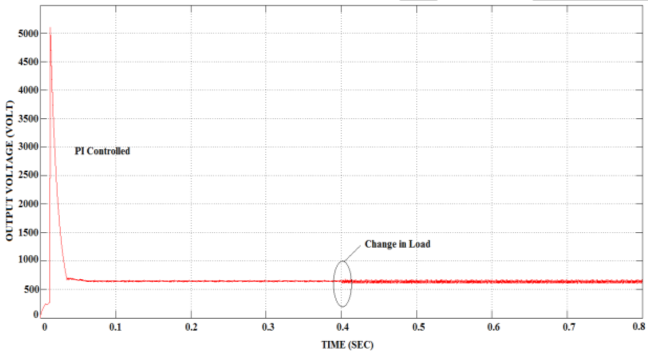


**Figure 10. Output voltage of PI controlled DC-DC boost converter with variable load**

From the graph, it is obvious that voltage oscillation is reduced by the application of PI controller. But the peak overshoots increases drastically. It demands an intelligent controller to reduce voltage oscillation as well as the peak overshoot.

Then the system is analyzed using proposed Accelerated Fuzzy PI controller with the same loading condition as in case of PI controller. Figure 11 shows the voltage output of Accelerated Fuzzy PI controlled boost converter.

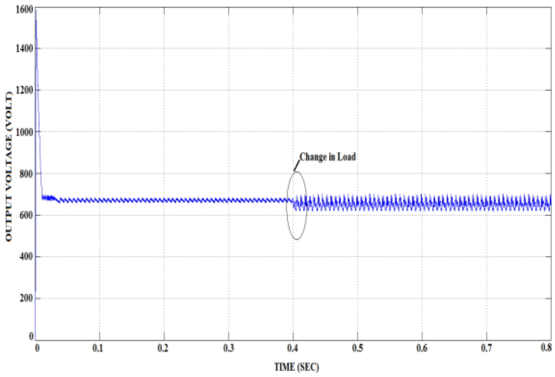


**Figure 11. Output voltage of AFPI controlled DC-DC boost converter with variable load**

From the graph, it is observed that voltage stability is improved by the application of Accelerated Fuzzy PI controller.

**TABLE III Trade-Off Analysis Of Accelerated Fuzzy Control With Pi Controller**

| Parameter | PI Controller | Proposed Accelerated Fuzzy Controller |
|---|---|---|
| Peak overshoot | High | Medium |
| Steady state Error (%) | 5.15 | 1.5 |
| Voltage Ripple during steady state (%) | 4.41 | 2.9 |
| Voltage Ripple during dynamic state (%) | 11.8 | 10.9 |

## VI. CONCLUSION

The closed-loop converters analyzed in this paper provides quality power and stable voltage which is mandatory for all electric consumers. In a dynamic state PI controlled boost converter offers reduced ripple compared to the open loop converter. However, it produces high overshoot and steady-state error comparatively. The proposed Accelerated fuzzy PI controller overcomes these crisis. It produces less voltage ripple in the steady state as well as in the dynamic state. Peak overshoot is less compared to the PI controller and it provides the merit of reduced voltage stress in the switching device of the power converter. Reduced steady-state error and voltage stress improves the performance of the load. Hence, from the trade-off inference, it is quite evident that accelerated fuzzy PI controller based boost converter enhancess the time response specifications when compared to its PI controller counterpart. Thus it is validated that the proposed AFPIC is cost-effective, reliable and provides stable quality output voltage.

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## REFERENCES

[1] Sci and Berkeley, Special issue on digital control in power electronics. IEEE Trans. Power Electron. 18(1) Vol.II/II, 2003

[2] Sira-Ramirez.H: Sliding motions in bilinear switched networks, IEEE Trans. Circuits Systems, vol. CAS-34, p. 919-933, Aug.1987


DOI : 10.18231/2454-9150.2018.0430

[3] Sira-Ramirez.H: Design of PI controllers for DC-to-DC power supplies via extended linearization, Int. J. Control, 51(3), p.601-620, 1990

[4] Ramirez-Garcia.P, R. De Keyser: Model Based Predictive Control of Switched Mode Power Supplies, Proc. of the European Control Conf. – ECC2001, Seminario de Vilar, Porto, Portugal, 2001, p.3771-3776

[5] Lazar.M, R. De Keyser: Non-linear predictive control of a DC-to-DC converter. SPEEDAM'04 Symposium on Power Electronics, Electrical Drives, Automation & Motion, 16-18 June, Capri, Italy; 5p paper nr. A206.

[6] De Keyser.R: Model Based Predictive Control. Invited Chapter in, "UNESCO Encyclopedia of Life Support Systems (EoLSS)". EoLSS Publishers Co Ltd, Oxford, 2003 (www.eolss.net).

[7] Escobar.G, R. Ortega, H. Sira-Ramirez: J.P. Vilain and I. Zein: An experimental comparison of several nonlinear controllers for power converters, IEEE Control Systems, 19(1), p.66-82, 1999.

[8] Raviraj, V.S.C. and P.C. Sen (1997). Comparative study of proportional-integral, sliding mode, and fuzzy logic controllers for power converters. *IEEE Trans. On Ind. App.*, Vol. 33, pp. 518-524.

[9] Viswanathan, K., D. Srinivasan and R. Oruganti (2002). A universal fuzzy controller for a nonlinear power electronic converter. *IEEE Inter. Conf. On Fuzzy Systems*, Vol. 1, pp. 46-51.

[10] Diordiev, A., O. Ursaru, M. Lucanu and L. Tigaeru (2003). A hybrid PID-fuzzy controller for dc/dc converters. *Inter. Symp. On Signals, Circuits and Systems*, Vol. 1, pp. 97-100.

[11] Erickson, R.W. and D. Maksimovic (1999). *Fundamentals of Power Electronics*, Kluwer Academic Publishers, Boston, Dordrecht, London.

[12] Kim J H, S.J Oh, *A Fuzzy PID Controller for Nonlinear and Uncertain Systems*, soft computing *4*, Springer-Verlag, 2000.

[13] Limei Wang, Mingxiu Tian and Yanping Gao, 2007, *Fuzzy Self-adapting PID Control of PMSM Servo System*,IEEE proceeding from Electric Machines & Drives Conference, Vol.1, No.10, pp.860-

 DOI : 10.18231/2454-9150.2018.0430 