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# Decomposed Fuzzy PID Controller for Power Inverters Regulation: An Overview

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## *Abstract*

The aim of this paper is to examine the various decomposed Fuzzy PID control structures in literature and to classify them into different categories. An important attribute of decomposed Fuzzy PID controllers is its structural simplicity. In this paper, decomposed Fuzzy PID controllers are classified as Fuzzy + Conventional type controller and Fuzzy + Fuzzy type controller. Structural construction and output control laws of these controllers will be discussed. Their merits and drawbacks are highlighted. Based on the critical discussions, a new structure of Fuzzy PID controller is proposed. It is based on cascaded structure which reflects simpler design flow and parameters tuning. Other advantages of the proposed Fuzzy PID structure are the reduction of tuning parameters and rules of the Fuzzy controller. The controller is useful for power inverter designers who required fast, simple and precise controllers.

***Keywords:*** *fuzzy logic; decomposed PID; fuzzy PID*

## 1. Introduction

Inverter is the most crucial component for dc to ac power conversion systems such as photovoltaic system, uninterruptable power supplies, induction heaters etc. The characteristic of an inverter is in the quality of its output voltage. For a well-designed inverter, regardless of type of load connected, the output is expected to be in stable and clean ac form [1]. Though, with the involvement of power electronics converter as loads, the inverter if forced to provide non-linear currents. This non-linearity in the current deteriorates the quality of the output voltage. Many cases, due to the severity of the distortion, of system failure have been reported [2-4]. Moreover, harmonics generated due to high current and voltage switching of the inverter is a serious threat for sensitive equipments. Maintaining a high quality voltage output, under any load condition, is a challenging task for the inverter designer. The key is to employ an appropriate controller. Fig. shows block diagram of the general inverter system [5]. The main components of the system are inverter circuit topology, switching circuit and controller. For many years, numerous inverter control techniques have been proposed to achieve fast transient response and to eliminate output voltage distortions under non-linear loads. Although the controllers are designed for the same objectives, they differ markedly in terms of concept, complexities and with varying degree of performance. For instance, some controllers are good in providing fast transient response and are immune to parameters variations. Though, those features are achieved with complex implementation. There are less complicated controllers that can produce comparable performance but require simpler implementation.



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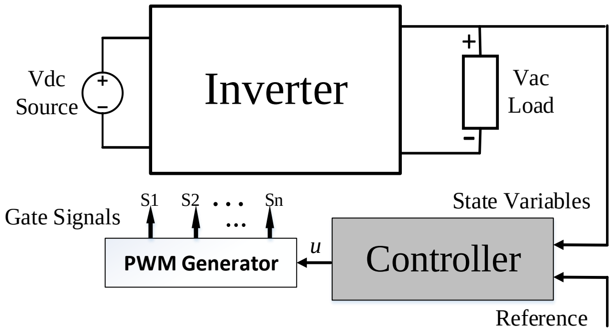


**Fig. 1:** Block Diagram of the Inverter System

Among the prominent controllers used in regulating an inverter are PID [6-8], Sliding mode [9-13] Neural Network [14-16] and Fuzzy Logic [17-21]. Fuzzy logic is considered as non-model based controller. Its control design mimics the way of human thinking of solving problems. It is linguistic based control which lack of design procedures. Hence optimal control performance is usually hard to achieve. To overcome their lacking, Fuzzy logic is combined with other controllers i.e. PI, PD and PID. Fuzzy PI controllers are preferred more than fuzzy PD controllers as fuzzy PD controllers are not able to eliminate steady state errors [22]. However, for higher order process transient response of Fuzzy PI controller show poor performance due to integration operation. The application of FPIC for power converters regulation can be found in [23-26]. To obtain overall superior performance, fuzzy PID controllers are preferred [27, 28]. This is the combination of FLC and PID controller. Lots of research had been done on fuzzy logic control application its use in power converter control was mainly in the field of dc/dc converters [29-39]. Even though Inverter is an integral part of the industrial Engineering few papers proposed the use of Fuzzy Logic for inverters control. Out of these only a few papers proposed Fuzzy PID controllers for inverter regulation, such as [37-39]. However, performance of Fuzzy PID controller is much betters then the Fuzzy PI and Fuzzy PD controllers.

Fuzzy PID controllers, eliminates the error of both Fuzzy PI and Fuzzy PD controller [29], provide a promising option for industrial applications with many desirable features [40, 41]. Problem with the conventional Fuzzy PID controller is that either they required tuning of the complex three-dimensional rule tables if there are three input variables to the controller or tuning of the large number of rules due to large number of membership functions [42]. Many strategies and designs had been reported in literature to simplifying the complexities of the Fuzzy PID controllers use for inverter regulation [37-43] but this review limits the scope to the ones related to Decomposed Fuzzy PID Controller only.

In recent years, lots of research is going on decomposed Fuzzy PID control structures [44-51]. Since the decomposed Fuzzy PID control structures are one of the simple solutions to address the complexities of the conventional Fuzzy PID controllers. These are the either the combination of fuzzy controller and conventional controller or the combination of two fuzzy controllers [45-48]. Due to the involvement of conventional converter overall performance of the later combination is better.

This paper presents a critical review on different decomposed Fuzzy PID Controller structures reported in the literature and also proposed a new simplified decomposed Fuzzy PID controller for power inverter regulation. Structure of the paper is as follows. Next section deals with the analysis of the different forms of decomposed Fuzzy PID structures presented in the literature along with their configurations and control law. Section 3 presents the proposed Fuzzy PID structure while section 4 consists of discussion and conclusion.

## 2. Decomposed Fuzzy PID Controller

In literature various fuzzy controller have been proposed. They can be divided into two categories i.e. Fuzzy PID and Fuzzy Non-PID. On the bases of structure Fuzzy PID controllers can further grouped as Decomposed Fuzzy PID and Conventional Fuzzy PID. Fuzzy PID controller classification is sketched in

Fig. 2 and Fig. 3. Numerous forms of decomposed PID fuzzy logic controllers have been reported have been tested and compared [44-48]. In general, according to the type of controllers involved in their way of construction Decomposed Fuzzy PID controller can be classified into two major categories:

***Fuzzy + Conventional type controller***

It is a combination of fuzzy controller and conventional controller. One is the conventional controllers such as P, I, PI, PD etc. and the other part consist of controllers such as Fuzzy P, Fuzzy PI, Fuzzy I, etc. To perform PID control action both the parts are integrated into a single unit. For example, Fuzzy I + PD form, Fuzzy PI + D form, and so on.

***Fuzzy + Fuzzy type Controller***

Both the parts of this decomposed controller constitute of Fuzzy Logic controllers i.e. it is a combination of two fuzzy controllers. Example of such type controllers are Fuzzy PI + Fuzzy D form, Fuzzy PD + Fuzzy I form, Fuzzy P + Fuzzy I + Fuzzy D from, and so no.

On the basis of the above mentioned categories various studies on the decomposed Fuzzy PID controller in literature will be examined and classified in the next section.

## 3. Fuzzy + Conventional type Decomposed Fuzzy PID Controllers

### *A. Fuzzy P + ID*

Li in [51] proposed Fuzzy P + ID controller. Fig. 2(a) shows the structure of a simple Fuzzy P + ID controller. Its control law consists of the Fuzzy P controller and conventional ID controller. The output expression of the controller is represented by (1). In this structure, Fuzzy P controller plays an important role as it is accountable of improving the rise time and overshoot. Response flatness and system stability is controlled by the Conventional D part where as integral part reduces the steady state error of the response.

$$u(k) = u_{Fuzzy\,P}(k) + u_I(k) + u_D(k) \qquad (1)$$

### *B. Fuzzy PI + D*

In 1995, Li and Gatland proposed Fuzzy PI + D controller in their paper [52]. Its control law consists of the Fuzzy PI and derivative control action of the process output and is given by (2). Fig. 2(b) shows the structure of a Fuzzy PI + D control system. The benefit of this structure is that the derivative control is implemented on the output, avoiding derivative kicks for step set point changes.

$$u(k) = u_{Fuzzy\,PI}(k) + u_D(k) \qquad (2)$$

### *C. Fuzzy I + PD*

In Fuzzy I + PD controller, Integral part of the controller is tuned by using Fuzzy Logic control and the proportional and derivative action is carried out using conventional method. The control law of the output can be expressed by (3). Fig. 2(c) shows the structural construction of the Fuzzy I + PD controller.

$$u(k) = u_{Fuzzy\,I}(k) + u_P(k) + u_D(k) \qquad (3)$$

### *D. Fuzzy PD + I*

Fuzzy PD + I controller can be achieved by combining Fuzzy PD controller with conventional integral controller. In this controller error and change of error both are given as input to the Fuzzy PD controller whereas the Integral controller takes error signal as its input. The rule base of the controller is a two Dimensional rule table. Structural construction of the controller is shown in Fig. 2(d) and its control law is given by (4).

$$u(k) = u_{Fuzzy\,PD}(k) + u_I(k) \quad (4)$$

***E. Fuzzy D + PI***

Fuzzy PID controller can also be realized as a decomposed structure constitutes Fuzzy D and conventional PI controller. In this configuration, the conventional PI controller used can be form either by using two separate Proportional and Integral controllers or by combining Proportional and Integral controllers into a single unit to form PI controller. Control law for this controller is given by (5). Change of error is taken as the only input to the Fuzzy D controller therefore its rule base is a one dimensional rule table. The structural configuration of the Fuzzy D + PI controller is shown in Fig. 2(e).

$$u(k) = u_{Fuzzy\,D}(k) + u_{PI}(k) \quad (5)$$

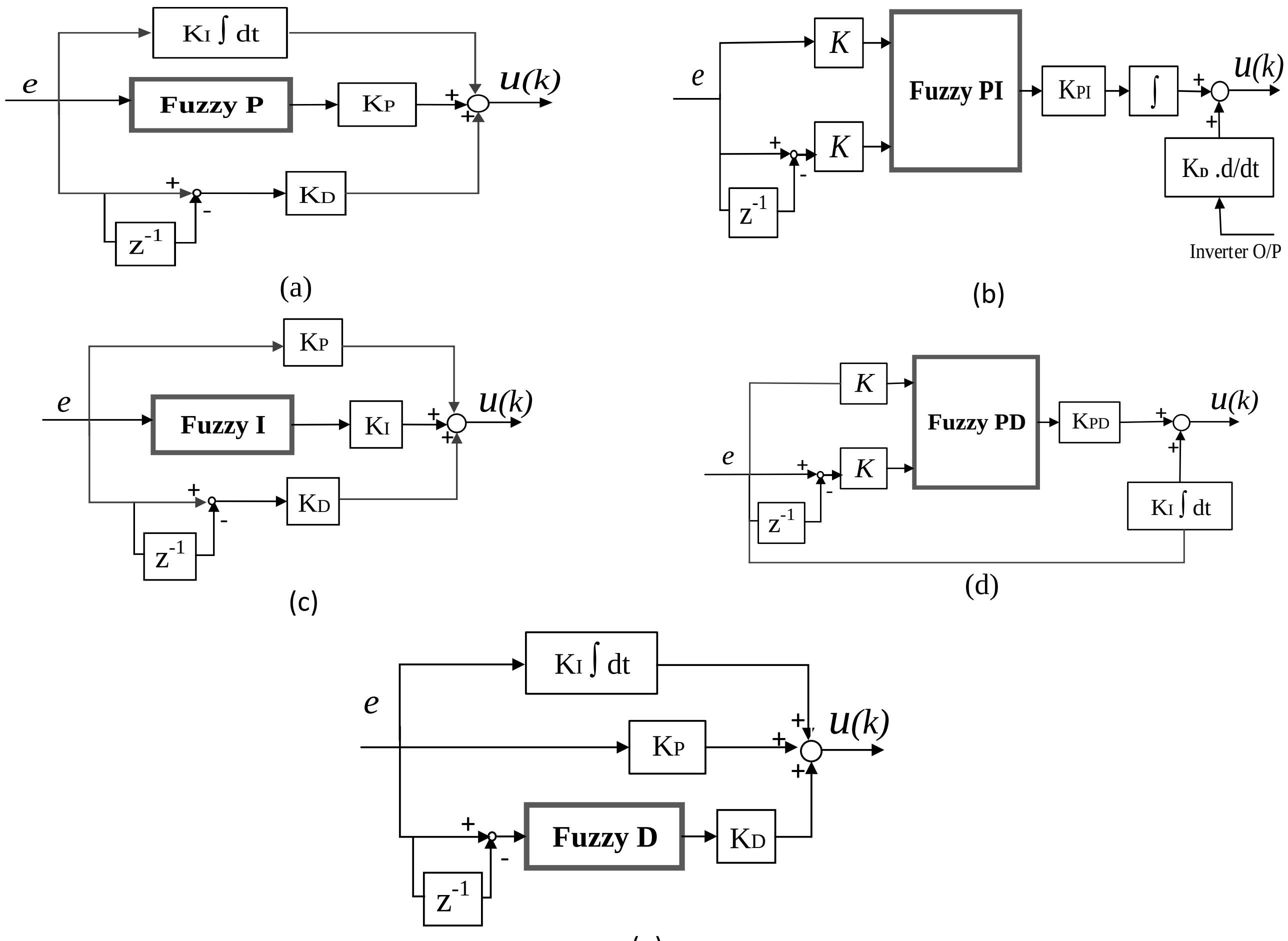


**Fig. 2:** Different structures of the decomposed Fuzzy + Conventional type PID controllers (a) Fuzzy P + ID form. (b) Fuzzy PI + D form. (c) Fuzzy I + PD form. (d) Fuzzy PD + I form. (e) Fuzzy D + PI form.

## 4. Fuzzy + Fuzzy type Decomposed Fuzzy PID Controllers

***A. Fuzzy I + Fuzzy PD***

Li and Ng in [53] proposed the structure of the Fuzzy I+ Fuzzy PD controller. In this structure, Control law is obtained by the summation of Fuzzy PD control action and Fuzzy I control action together and is expressed by equation (6). The control structure of Fuzzy I + Fuzzy PD controller is shown in Fig. 3(a).

The characteristic of the Fuzzy I + Fuzzy PD is a combination of a one-dimensional and two-dimensional rule base for the Integral and PD control respectively.

$$u\ (k) = u_{\text{Fuzzy I}}\ (k) + u_{\text{Fuzzy PD}}\ (k) \quad (6)$$

### *B. Fuzzy P + Fuzzy ID*

Fig. 3(b) shows the structure of simple Fuzzy P + Fuzzy ID controller. It is a combination of Fuzzy P and Fuzzy ID controller. Fuzzy P has error signal as its input whereas Fuzzy ID has two inputs i.e. integral of error and change of error. The knowledge base of this controller constitute of one-dimensional and two-dimensional rule table for Fuzzy P and Fuzzy ID respectively. Equation (7) expressed the Control law, which is a summation of Fuzzy P control action and Fuzzy ID control action.

$$u\ (k) = u_{\text{Fuzzy P}}\ (k) + u_{\text{Fuzzy ID}}\ (k) \quad (7)$$

### *C. Fuzzy PI + Fuzzy D*

Fuzzy PI + Fuzzy D controller is formed by combining Integral and Proportional controller as one unit and Fuzzy D as a separate controller. The knowledge base of this form of PID controller constitute of two-dimensional rule table for Fuzzy PI and one-dimensional rule table for derivative control action. Error and change in error is taken as the two inputs to the Fuzzy PI controller, output of Fuzzy interface is then integrated to get Proportional-Integral action. Fuzzy D controller takes change of error as its input. Simple control structure of Fuzzy PI + Fuzzy D controller and its control law is representation by Fig. 3(c) and equation (8) respectively.

$$u\ (k) = u_{\text{Fuzzy PI}}\ (k) + u_{\text{Fuzzy D}}\ (k) \quad (8)$$

### *D. Fuzzy PD + Fuzzy PI*

The Fuzzy PD + Fuzzy PI controller is presented in [52, 54] by Li et al and Kwok et al respectively. It is a parallel combination of a Fuzzy PD and a Fuzzy PI controller. Its structure is shown Fig. 3(d). The knowledge base of this controller constitute of two two-dimensional rule tables each for Fuzzy PD and Fuzzy PI. The control law can be expressed by equation (9).

$$u\ (k) = u_{\text{Fuzzy PI}}\ (k) + u_{\text{Fuzzy PD}}\ (k) \quad (9)$$

### *E. Fuzzy P + Fuzzy I + Fuzzy D*

Fuzzy PID controller can also be formed by combining three Fuzzy controllers i.e. Fuzzy P, Fuzzy I and Fuzzy D. In this structure, there exist three distinct rule bases using only error as the input variable to generate three separate fuzzy proportional actions [54-56]. This is also an example of a single input fuzzy PID controller. It has although one dimensional rule table. But due to many rule tables large numbers of parameters are to be tuned. The structure of a simple control system of Fuzzy I + Fuzzy P + Fuzzy D controller is shown Fig. 3(e). Equation (10) gives the control law of the control output process.

$$u\ (k) = u_{\text{Fuzzy P}}\ (k) + u_{\text{Fuzzy I}}\ (k) + u_{\text{Fuzzy D}}\ (k) \quad (10)$$

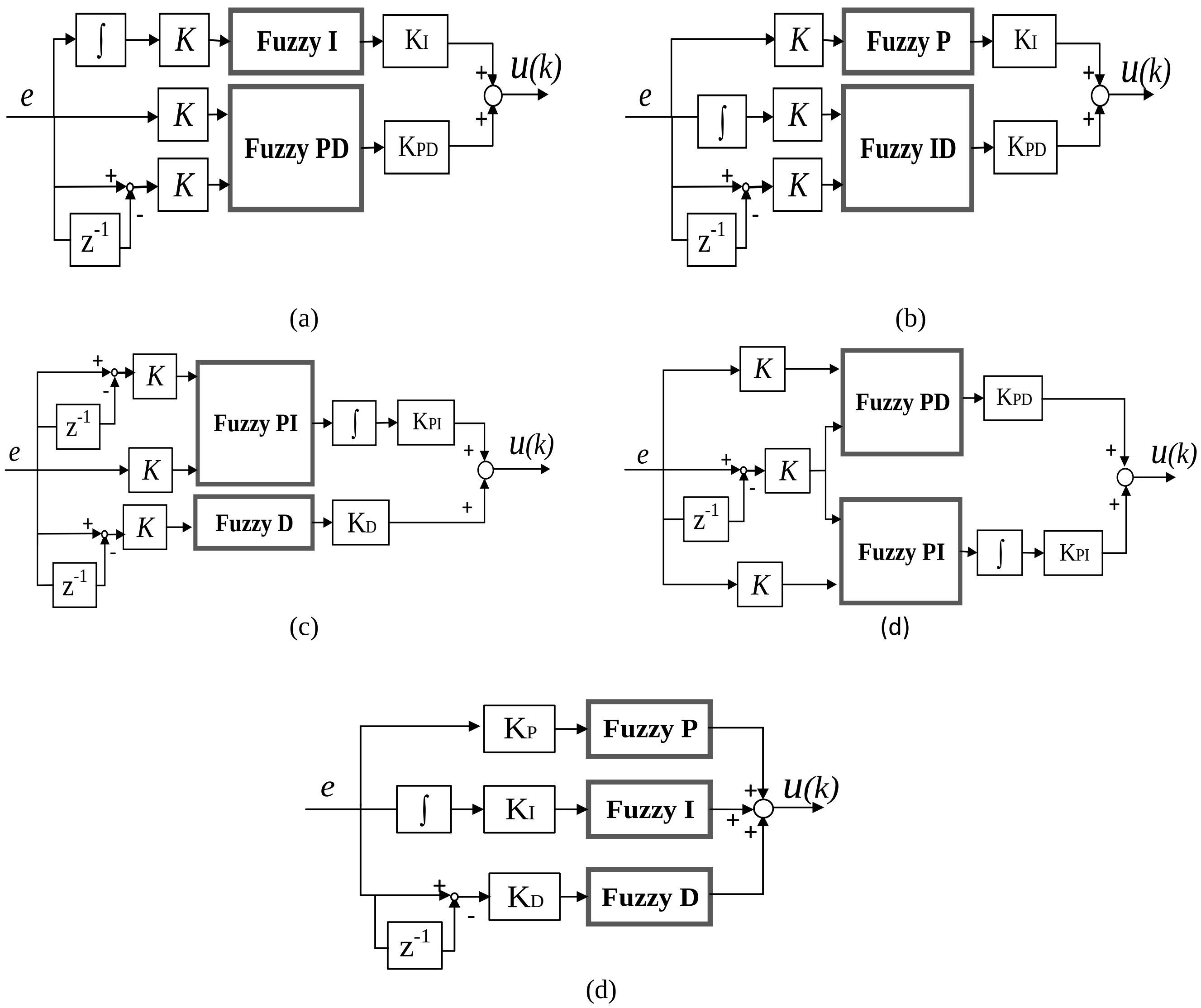


**Fig. 3**: Different structures of the decomposed Fuzzy + Fuzzy type PID controllers (a) Fuzzy I + PD form. (b) Fuzzy P + ID form. (c) Fuzzy PI + Fuzzy D form. (d) Fuzzy PI + Fuzzy PD form. (e) Fuzzy P + Fuzzy I + Fuzzy D form.

## 5. Proposed Fuzzy PID controller

Although the decomposed Fuzzy PID control structures presented in literature eliminate the complexity of the three-dimensional rule table process is still complex and time consuming due to the presence of large number of tuning parameters. Overcoming these issues, an improved form of simple decomposed Fuzzy PID controller is proposed. It is based on cascaded structure which reflects simpler design and effortless parameters tuning. The proposed controller is decomposed into two Fuzzy control stages. The knowledge rule base of each controller can be easily reduced to one-dimensional rule table by applying the concept of signed distance method [25, 35]. The structure of the proposed controller is shown in Fig. 4. Error ($e$) and change of error ($\dot{e}$) is taken as input of the controller at first stage. Controller at both stages are cascaded such that the output of the first controller along with change of change of error ($\ddot{e}$) given as the inputs to the second controller. Control law for the proposed PID controller is represented by equation (11).

$$u\,(k) = G_P\, e(k) + G_I \int \dot{e}(k) + G_D\, \ddot{e}\,(k) \quad (11)$$

Where,

$$G_P = K_P.A\,; \quad G_I = K_I.A\,; \quad G_D = K_D$$

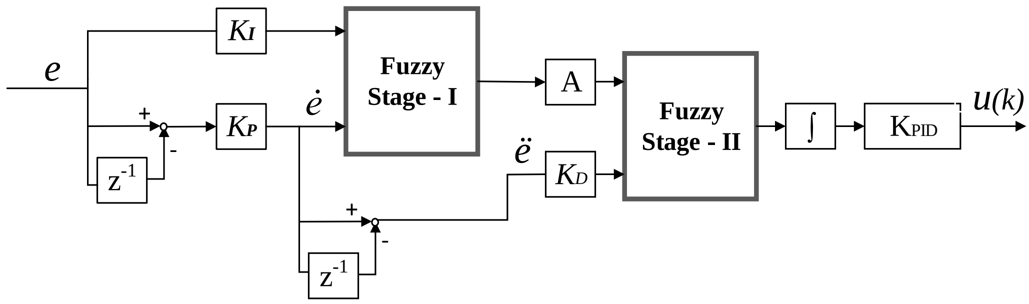


**Fig. 4:** Proposed cascade structured decomposed Fuzzy PID controller.

## 6. Discussion

Numerous structures of the decomposed Fuzzy controllers found in the literature has been discussed in the in this paper. These controllers can be classified into Fuzzy + Conventional type and Fuzzy + Fuzzy type decomposed Fuzzy PID controllers. Due to the presence of the conventional part it has been observed that the later type shows better performance. Fuzzy + Fuzzy type controllers, shown in Fig. 3, constitute of either two two-dimensional rule table or a two-dimensional and one one-dimensional rule table or three separate one-dimensional rule tables. Due to the large number of tuning parameters, optimum and efficient tuning of the controller will become complex and lengthy process. An improved form of the decomposed Fuzzy PID control structure is proposed in this paper. The design is to improve the performance, complexity and process time of the controller by reducing the number of rules and tuning parameters. First the controller is decomposed into two stages such that output of the first stage is fed as the input to the second stage to form cascaded structure. Proposed structure has improved performance then the convention Fuzzy PID controller.

## Conclusion

In this paper a review of several decomposed Fuzzy PID control structures is carried out. The decomposed Fuzzy PID controllers are classified as Fuzzy + Conventional type controller and Fuzzy + Fuzzy type controller. Their merits and drawbacks have been highlighted. Based on the critical discussions, a new structure of Fuzzy PID controller is proposed. It is based on cascaded structure which reflect simpler design flows and parameter tuning.

## References

[1]. N. Mohan and T. M. Undeland, *Power electronics: converters, applications, and design*: John Wiley & Sons, 2007
[2]. Deng, H., Oruganti, R., and Srinivasan, D. A Simple Control Method for High-Performance UPS Inverters through Output-Impedance Reduction. IEEE Transaction on Industrial Electronics. 2008. 55(2): 888-898.
[3]. Habetler, T. G., and Harley, R. G. Power Electronic Converter and System Control. Proceeding of the IEEE. 2001. 89(6): 913-925.
[4]. Sanchis, P., Ursaea, A., Gubia, E., and Marroyo, L. Boost DC-AC Inverter: A New Control Strategy. IEEE Transaction on Power Electronics. 2005. 20(2): 343-353.
[5]. M. S. Bin Arif and S. Md Ayob, "A novel single phase five-level photovoltaic based grid-connected inverter," in Energy Conversion (CENCON), 2014 IEEE Conference on, 2014, pp. 325-330.

[6]. B. Y. Husodo and S. M. Ayob, "Design of Proportional Integral Derivative (PID) controller for impedance-source inverter," in Computer Applications and Industrial Electronics (ICCAIE), 2011 IEEE International Conference on, 2011, pp. 121-125.
[7]. M. P. Kazmierkowski and F. A. Silva, "Power Electronics Handbook, Third Edition (Rashid, M.H.; 2011) [Book News]," *Industrial Electronics Magazine, IEEE,* vol. 5, pp. 54-55, 2011.
[8]. Y. Chen, "SPWM Inverter Closed-Loop PID Control System", Advanced Materials Research, Vols. 219-220, pp. 1367-1370, Mar. 2011.
[9]. Ramos, R. R., Domingo, B., Fossas, E., and Guinjoan, F. A Fixed-frequency Quasi-Sliding Control Algorithm: Application to Power Inverters Design by Means of FPGA Implementation. IEEE Transaction on Power Electronics. 2003. 18(1): 344-355.
[10]. Biel, D., Guinjoan, F., Fossas, E. and Chavarria, J. Sliding-mode Control Design of a Boost-buck Switching Converter for AC Signal Generation. IEEE Transaction on Circuits and Systems. 2004. 51(8): 1539-1551.
[11]. Tai, T. –L., and Chen, J. –S. UPS Inverter Design using Discrete-time Slidingmode Control Scheme. IEEE Transaction on Industrial Electronics. 2002. 49(1): 67-75.
[12]. Biel, D., Fossas, E., Guinjoan, F., Alarcon, E., and Poveda, A. Application of Sliding-Mode Control to the Design of a Buck-Based Sinusoidal Generator. IEEE Transaction on Industrial Electronics. 2001. 48(3): 563-571.
[13]. Yan, W., Hu, J., Utkin, V., and Xu, L. Sliding Mode Pulse Width Modulation. IEEE Transaction on Power Electronics. 2008. 23(2): 619-626.
[14]. W. Rong-Jong, C. Meng-Wei, and L. Yao-Kai, "Design of Adaptive Control and Fuzzy Neural Network Control for Single-Stage Boost Inverter," Industrial Electronics, IEEE Transactions on, vol. 62, pp. 5434-5445, 2015.
[15]. D. Heng, R. Oruganti, and D. Srinivasan, "Analysis and Design of Iterative Learning Control Strategies for UPS Inverters," Industrial Electronics, IEEE Transactions on, vol. 54, pp. 1739-1751, 2007.
[16]. S. Xiao, M. H. L. Chow, F. H. F. Leung, X. Dehong, W. Yousheng, and Y. S. Lee, "Analogue implementation of a neural network controller for UPS inverter applications," Power Electronics, IEEE Transactions on, vol. 17, pp. 305-313, 2002.
[17]. H. M. Hasanien and M. Matar, "A Fuzzy Logic Controller for Autonomous Operation of a Voltage Source Converter-Based Distributed Generation System," Ieee Transactions on Smart Grid, vol. 6, pp. 158-165, Jan 2015.
[18]. A. El Khateb, N. Abd Rahim, J. Selvaraj, and M. N. Uddin, "Fuzzy-Logic-Controller-Based SEPIC Converter for Maximum Power Point Tracking," IEEE Transactions on Industry Applications, vol. 50, pp. 2349-2358, Jul-Aug 2014.
[19]. S. M. Ayob, Z. Salam, and N. A. Azli, "A new optimum design for a single input fuzzy controller applied to DC to AC converters," Journal of Power Electronics, vol. 10, pp. 306-312, 2010.
[20]. A. Aceves-Lopez and J. Aguilar-Martin, "A simplified version of mamdani's fuzzy controller: the natural logic controller," Fuzzy Systems, IEEE Transactions on, vol. 14, pp. 16-30, 2006.
[21]. W. Tsai-Fu, C. Chien-Hsuan, and C. Yu-Kai, "A fuzzy-logic-controlled single-stage converter for PV-powered lighting system applications," Industrial Electronics, IEEE Transactions on, vol. 47, pp. 287-296, 2000.
[22]. Q. Wu Zhi and M. Mizumoto, "PID type fuzzy controller and parameters adaptive method," Fuzzy Sets and Systems, vol. 78, pp. 23-35, 2/26/ 1996.
[23]. I. Sefa, N. Altin, S. Ozdemir, and O. Kaplan, "Fuzzy PI controlled inverter for grid interactive renewable energy systems," IET Renewable Power Generation, 2015.
[24]. P. C. Thanh, A. Shen, P. Q. Dzung, and N. B. Anh, "Self-tuning fuzzy PI-type controller in z-source inverter for hybrid electric vehicles," International Journal of Power Electronics and Drive Systems (IJPEDS), vol. 2, pp. 353-363, 2012.
[25]. S. M. Ayob, N. A. Azli, and Z. Salam, "PWM DC-AC Converter Regulation using a Multi-Loop Single-Input Fuzzy PI Controller," Journal of Power Electronics, vol. 9, pp. 124-131, Jan 20 2009.
[26]. Chen, Y. –K., Yang, C. –H., and Wu, Y. –W. Robust Fuzzy Controlled Photovoltaic Power Inverter with Taguchi Method. IEEE Transaction on Aerospace and Electronic Systems. 2002. 38(3): 940-954.
[27]. S. Ayob, N. Azli, and Z. Salam, "Single input PI-fuzzy controller for single phase inverter system," International Review of Electrical Engineering (IREE), vol. 3, pp. 418-425, 2008.
[28]. M. Mizumoto, "Realization of PID controls by fuzzy control methods," Fuzzy Sets and Systems, vol. 70, pp. 171-182, 3/20/ 1995.
[29]. Q. Wu Zhi and M. Mizumoto, "PID type fuzzy controller and parameters adaptive method," Fuzzy Sets and Systems, vol. 78, pp. 23-35, 2/26/ 1996.
[30]. Wu, T.-F., Chang, C.-H., and Chen, Y.-H. A Fuzzy Logic Controlled Single-stage Converter for PV-powered Lighting System Applications. IEEE Transaction on Industrial Electronics. 2000. 47(2): 287-296.
[31]. K. Viswanathan, R. Oruganti, and D. Srinivasan, "Nonlinear function controller: A simple alternative to fuzzy logic controller for a power electronic converter," IEEE Transactions on Industrial Electronics, vol. 52, pp. 1439-1448, Oct 2005.
[32]. K. Guesmi, N. Essounbouli, and A. Hamzaoui, "Systematic design approach of fuzzy PID stabilizer for DC–DC converters," Energy Conversion and Management, vol. 49, pp. 2880-2889, 10// 2008.
[33]. C. Cecati, F. Ciancetta, and P. Siano, "A Multilevel Inverter for Photovoltaic Systems With Fuzzy Logic Control," Industrial Electronics, IEEE Transactions on, vol. 57, pp. 4115-4125, 2010.
[34]. M. Ranjani and P. Murugesan, "Optimal fuzzy controller parameters using PSO for speed control of Quasi-Z Source DC/DC converter fed drive," Applied Soft Computing, vol. 27, pp. 332-356, Feb 2015.

[35]. F. Taeed, Z. Salam, and S. M. Ayob, "FPGA Implementation of a Single-Input Fuzzy Logic Controller for Boost Converter with the Absence of an External Analog-to-Digital Converter," IEEE Transactions on Industrial Electronics, vol. 59, pp. 1208-1217, Feb 2012.
[36]. Y. Kanthaphayao and V. Chunkag, "Current-sharing bus and fuzzy gain scheduling of proportional-integral controller to control a parallel-connected AC/DC converter," Iet Power Electronics, vol. 7, pp. 2525-2532, Oct 2014.
[37]. M. Louzazni and E. Aroudam, "Intelligent PID-Fuzzy logic control for three-phase grid-connected photovoltaic inverter," in Intelligent Systems: Theories and Applications (SITA-14), 2014 9th International Conference on, 2014, pp. 1-6.
[38]. L. Jia De, Q. Wu, W. Sun Zhen, and P. Xu, "A Switching-inverter power controller based on fuzzy adaptive PID," in Strategic Technology (IFOST), 2011 6th International Forum on, 2011, pp. 695-699.
[39]. F. Ronilaya and H. Miyauchi, "A New Implementation of PID-Type Fuzzy Controller for a Battery Grid-Supporting Inverter in an Autonomous Distributed Variable-Speed Wind Turbine," IEEJ Transactions on Electrical and Electronic Engineering, vol. 10, pp. 134-143, Mar 2015.
[40]. Abdullah I. Al-Odienat, Ayman A. Al-Lawama, “The Advantages of PID Fuzzy Controllers Over the Conventional Types”, American Journal of Applied Sciences 5, 653-658, 2008.
[41]. K. D. Sharma, M. Ayyub, S. Saroha, and A. F. Handershot, "Advanced Controllers Using Fuzzy Logic Controller (FLC) for Performance Improvement," International Electrical Engineering Journal (IEEJ) vol, vol. 5, pp. 1452-1458, 2014.
[42]. M. Louzazni and E. Aroudam, "Intelligent PID-Fuzzy logic control for three-phase grid-connected photovoltaic inverter," in Intelligent Systems: Theories and Applications (SITA-14), 2014 9th International Conference on, 2014, pp. 1-6.
[43]. L. Reznik, O. Ghanayem, and A. Bourmistrov, "PID plus fuzzy controller structures as a design base for industrial applications," Engineering Applications of Artificial Intelligence, vol. 13, pp. 419-430, 8/1/ 2000.
[44]. M. Golob, "Decomposed fuzzy proportional-integral-derivative controllers, ," Appl. Soft Comput. Vol.1, pp. 201–214, 2001.
[45]. B. M. Mohan and A. Sinha, "Analytical structure and stability analysis of a fuzzy PID controller," Applied Soft Computing, vol. 8, pp. 749-758, 1// 2008.
[46]. B.-G. Hu, G. K. Mann, and R. G. Gosine, "A systematic study of fuzzy PID controllers-function-based evaluation approach," Fuzzy Systems, IEEE Transactions on, vol. 9, pp. 699-712, 2001.
[47]. B. M. Mohan and A. Sinha, "The simplest fuzzy PID controllers: mathematical models and stability analysis," Soft Computing, vol. 10, pp. 961-975, 2006/08/01 2006.
[48]. W. Li, X. G. Chang, F. M. Wahl, and S. K. Tso, "Technical note Hybrid fuzzy P+ID control of manipulators under uncertainty," Mechatronics, vol. 9, pp. 301-315, 4/1/ 1999.
[49]. S. K. Pandey, "PID type fuzzy controller and parameters adaptive method," Fuzzy Sets and Systems, vol. 90, pp. 101-102, Aug 16 1997.
[50]. L. Wei, "Design of a hybrid fuzzy logic proportional plus conventional integral-derivative controller," Fuzzy Systems, IEEE Transactions on, vol. 6, pp. 449-463, 1998.
[51]. H. X. Li and H. B. Gatland, "Enhanced methods of fuzzy logic control," in Fuzzy Systems, 1995. International Joint Conference of the Fourth IEEE International Conference on Fuzzy Systems and The Second International Fuzzy Engineering Symposium., Proceedings of 1995 IEEE Int, 1995, pp. 331-336 vol.1.
[52]. K. C. Ng and Y. Li, "Reduced rule-base and direct implementation of fuzzy logic control systems," in Proc. World Congress IFAC, 1996, pp. 85-90.
[53]. D. Kwok, Z.-Q. Sun, and P. Wang, "Linguistic PID controllers for robot arms," in Control 1991. Control'91., International Conference on, 1991, pp. 341-346.
[54]. G. K. I. Mann, H. Bao-Gang, and R. G. Gosine, "Analysis of direct action fuzzy PID controller structures," *Systems, Man, and Cybernetics, Part B: Cybernetics, IEEE Transactions on,* vol. 29, pp. 371-388, 1999.
[55]. H. Bao-Gang, G. K. I. Mann, and R. G. Gosine, "A systematic study of fuzzy PID controllers-function-based evaluation approach," *Fuzzy Systems, IEEE Transactions on,* vol. 9, pp. 699-712, 2001.
[56]. S. M. Ayob, N. A. Azli, and Z. Salam, "A review on controllers for PWM inverters," in *Power and Energy Conference, 2008. PECon 2008. IEEE 2nd International*, 2008, pp. 589-593.