REVIEW ON DECOMPOSED FUZZY PID STRUCTURE FOR POWER INVERTERS REGULATION

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Graphical abstract
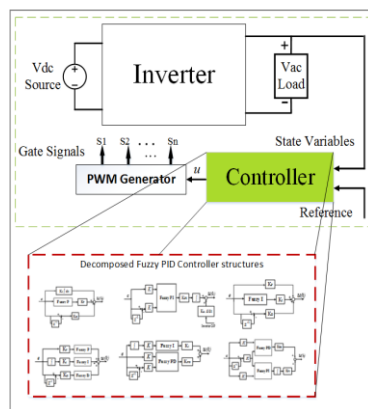
Abstract

The aim of this paper is to critically review prominent decomposed Fuzzy PID control structures. 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 yields 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. In addition, the proposed structure allows the usage of signed distance method. The application of the method reduces the computation burden significantly as the power inverter regulation needs very fast and precise computations.

Keywords: Fuzzy logic, Fuzzy PID, decomposed PID controller, decomposed fuzzy PID

Abstrak

Tujuan utama kertas kerja ini adalah untuk mengulas secara kritikal beberapa struktur terurai pengawal Kabur PID. Struktur binaan dan undang-undang keluaran kawalan untuk pengawal ini akan dibincangkan. Tumpuan perbincangan lebih terarah kepada mengenalpasti kelebihan dan kelemahan pengawal. Berdasarkan kepada perbincangan kritikal, struktur baharu pengawal Kabur PID terurai telah dicadangkan. Pengawal yang dicadangkan ini adalah berdasarkan kepada struktur berjujukan yang mana akan mempunyai aliran rekabentuk dan penalaan parameter yang lebih mudah. Kelebihan lain adalah pengurangan parameter talaan dan undang-undang pengawal kabur. Tambahan pula, struktur yang dicadangkan ini membenarkan penggunaan kaedah jarak bertanda. Aplikasi kaedah ini mengurangakn beban pengiraan dengan berkesan kerana pengaturan penyongsang kuasa ini memang memerlukan pengiraan yang pantas dan tepat.

Kata kunci: Logik kabur, pengawal PID kabur terurai; penyongsangkuasa

1.0 INTRODUCTION

Inverter is the most crucial component for dc to ac power conversion systems such as the uninterruptable power supplies (UPS), photovoltaic (PV) power conditioner, adjustable speed drives, induction heater etc. The main feature of a well designed inverter is its ability to provide clean and stable ac output voltage regardless of type of loads connected to it [1].

However, with the proliferations of power electronics converters connected as loads, the inverter is forced to provide non-linear currents. These highly distorted currents cause deterioration in the quality of its output voltage. There are numerous reported cases in which the severity of the distortion results in system failure [2-4]. In addition, the high voltage and current switching of the inverter generates harmonics which can be harmful to sensitive equipments. It has been always a

challenge for an inverter designer to maintain high quality sinusoidal voltage output under any load conditions. The key is to employ an appropriate controller. Figure1 shows block diagram of the general inverter system [5]. The main components of the system are inverter circuit topology, switching circuit and controller.

Presently, numerous inverter control techniques have been proposed to achieve fast transient response and to eliminate output voltage distortion under non-linear loads. These controllers are designed for the same objectives, but they differ markedly in terms of concept, complexities and with varying degree of performance. For instance, several controllers are good in providing fast transient response but highly sensitive to system's parameters changes and vice versa.

Among the prominent controllers used in regulating an inverter are PID [6-10], Sliding mode [11-13] Neural Network[14-17] and Fuzzy Logic[18-22]. Fuzzy logic is considered as non model based controller i.e. the design of its control parameters is independent from the mathematical model of the system. Its control design mimics the way of human thinking of solving problems. However, its linguistic based control lacks of design procedures. Hence optimal control performance is usually hard to achieve.
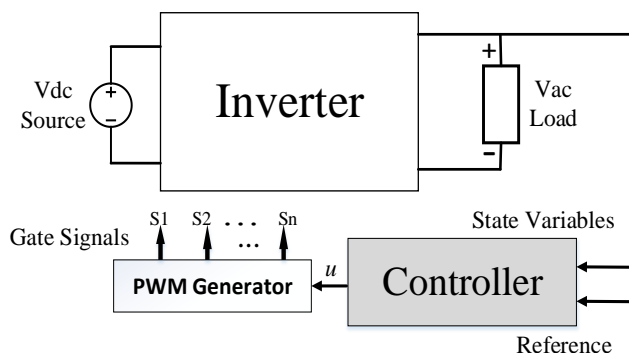

Figure 1 Block Diagram of the Inverter System

To overcome the 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 [23]. However, the former exhibits poor performance during the transient phase for higher order processes. This is due to their internal integration operation. The applications of Fuzzy PI (FPIC) for power converters regulation can be found in [24-26]. Fuzzy PID controllers are much better in overall performance as compared to the previous Fuzzy PI and PD controllers [27,28]. A lot of research have been conducted on fuzzy logic control application and its use in power converter control is mainly for dc/dc converters [29-39]. Refering to literature, very few papers reporting on theusage of Fuzzy Logic for inverters control. Out of these only a few papers proposed Fuzzy PID controllers for inverter regulation, such as [37-39].

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]. 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 [41]. Many strategies and designs have been reported in literature to simplifying the complexities of the Fuzzy PID controllers use for inverter regulation [37-42] but this review limits the scope to the ones related to Decomposed Fuzzy PID controller only.

In recent years, a lots of research is going on decomposed Fuzzy PID control structures [43-50]. 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 [44-47]. Due to the involvement of conventional converter overall performance of the later combination is better.

This paper presents a critical reviewon different decomposedFuzzy PID Controller structures reported in the literature and also proposed a new simplified decomposed Fuzzy PID controllerfor power inverter regulation. Structure of the paper is as follows. Next section deals with the analysis ofthe different forms of decomposed Fuzzy PID structurespresented 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.

2.0 DECOMPOSED FUZZY PID CONTROLLER

Figure 2 and Figure 3illustrate several forms of decomposed proportional-integral-derivative fuzzy logic controllers [44-48]. Referring to the structure, the controllers can be further distinguished as Fuzzy + Conventional controller and Fuzzy + Fuzzy controller types.

2.1 Fuzzy + Conventional Type Controller

It is a combination of fuzzy controller and conventional controller. One is the conventional controller (such as P, I, PI, PD) and the other part consisted of Fuzzy Logic controllers such as Fuzzy P, Fuzzy I and Fuzzy PI. 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 etc.

2.2 Fuzzy + Fuzzy Type Controller

In this type of controller, both parts of this decomposed controller constitute of Fuzzy Logic controllersi.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.

## 3.0 FUZZY + CONVENTIONAL TYPE DECOMPOSED FUZZY PID CONTROLLERS

3.1 Fuzzy P + ID

Li [50] proposed Fuzzy P + ID controller. Figure2(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 equation (1).The most important part in the fuzzy P + ID controller is the fuzzy P part because it is responsible forimproving overshoot and rise time. The conventional I part is responsible for reducing steady-state error, and the conventional D part is responsible for the stability of the system and for flatness of the response.

$$\cup (k) = \cup_{\text{Fuzzy P}} (k) + \cup_I (k) + \cup_D (k) \qquad (1)$$

3.2 Fuzzy PI + D

The Fuzzy PI + D controller was proposed by Li and Gatland [51]. The control law consists of the Fuzzy PI and derivative control action of the process output and is given by equation (2). Figure 2(b) shows the structure of a Fuzzy PI + D control system. This structure has the benefit of implementing derivative control on the output, avoiding derivative kicks for step set point changes.

$$\cup (k) = \cup_{\text{Fuzzy PI}} (k) + \cup_D (k) \qquad (2)$$
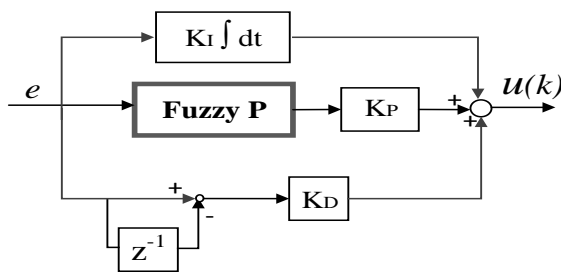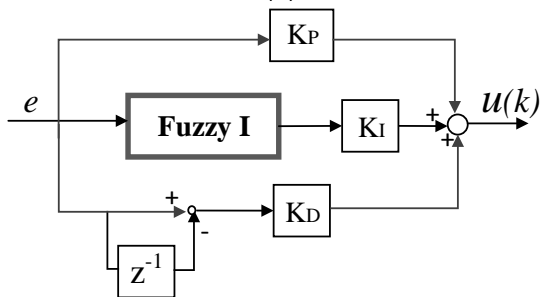
3.3 Fuzzy I + PD

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 equation (3). Figure 2(c) shows the structural construction of the Fuzzy I + PD controller.

$$\cup (k) = \cup_{\text{Fuzzy I}} (k) + \cup_P(k) + \cup_D(k) \qquad (3)$$
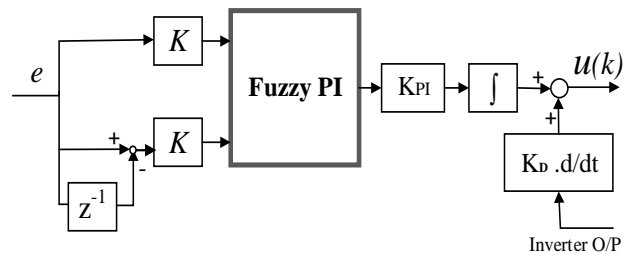
3.4 Fuzzy PD + I

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 where as 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 Figure 2(d) and its control law is given by equation (4).

$$\cup (k) = \cup_{\text{Fuzzy PD}} (k) + \cup_I (k) \qquad (4)$$

3.5 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 bycombiningProportional and Integral controllers into a single unit to form PI controller.Control law for this controller is given by equation (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 Figure 2(e).

$$\cup (k) = \cup_{\text{Fuzzy D}} (k) + \cup_{PI}(k) \qquad (5)$$
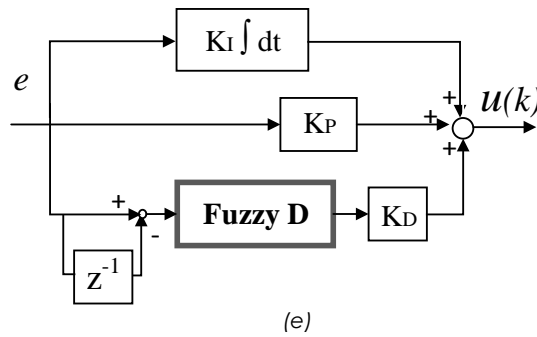

(a)

(b)

(c)

(d)

(e)
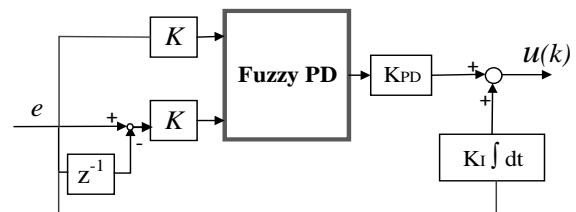
Figure2 Different structures of the decomposed Fuzzy + Conventional type PID controllers (a) Fuzzy IDform. (b) Fuzzy PI + D form. (c) Fuzzy I + PD form. (d) Fuzzy PD + I form. (e) Fuzzy D + PI form

4.0 FUZZY + FUZZY TYPE DECOMPOSED FUZZY PID CONTROLLERS

3.6 Fuzzy I + Fuzzy PD

Li and Ng [52] proposed the structure of the Fuzzy I+ Fuzzy PD controller. In this structure, the control law is obtained by the adding the output of Fuzzy PD control action and Fuzzy I control action together. The total output is expressed by equation (6). The structure of Fuzzy I + Fuzzy PD controller is shown in Figure 3(a). The characteristic of the Fuzzy I + Fuzzy PD is a combination of a two-dimensional rule base for the PD control and a one-dimensional rule base for the incremental integral control.

$$U(k) = U_{Fuzzy\ I}(k) + U_{Fuzzy\ PD}(k) \qquad (6)$$

4.1 Fuzzy P + Fuzzy ID

Figure 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. change of error and integral of error. The knowledge base is combination of one-dimensional rule table for Fuzzy P and two-dimensional rule table for Fuzzy ID. Equation (7) expressed the Control law, which is a summation of Fuzzy P control action and Fuzzy ID control action.

$$U(k) = U_{Fuzzy\ P}(k) + U_{Fuzzy\ ID}(k) \qquad (7)$$

4.2 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 Figure 3(c) and equation (8) respectively.

$$U(k) = U_{Fuzzy\ PI}(k) + U_{Fuzzy\ D}(k) \qquad (8)$$

4.3 Fuzzy PD + Fuzzy PI

The Fuzzy PD + Fuzzy PI controller is presented in [51, 53] by Li et al and Kwok et al, respectively. It is a parallel combination of a Fuzzy PD controller and a Fuzzy PI controller. The basic control diagram is shownFigure3(d).The fuzzy PD+ fuzzy PI controller consists of a two fuzzy controller in parallel. Its knowledge base is a combination of two-dimensional rule base for the PD control and another two-dimensional rule base for the PI control. The control law can be expressed by equation (9).

$$U(k) = U_{Fuzzy\ PI}(k) + U_{Fuzzy\ PD}(k) \qquad (9)$$

4.4 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 [53-54]. 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 Figure 3(e). Equation (10) gives the control law of the control output process.

$$U(k) = U_{Fuzzy\ P}(k) + U_{Fuzzy\ I}(k) + U_{Fuzzy\ D}(k) \qquad (10)$$
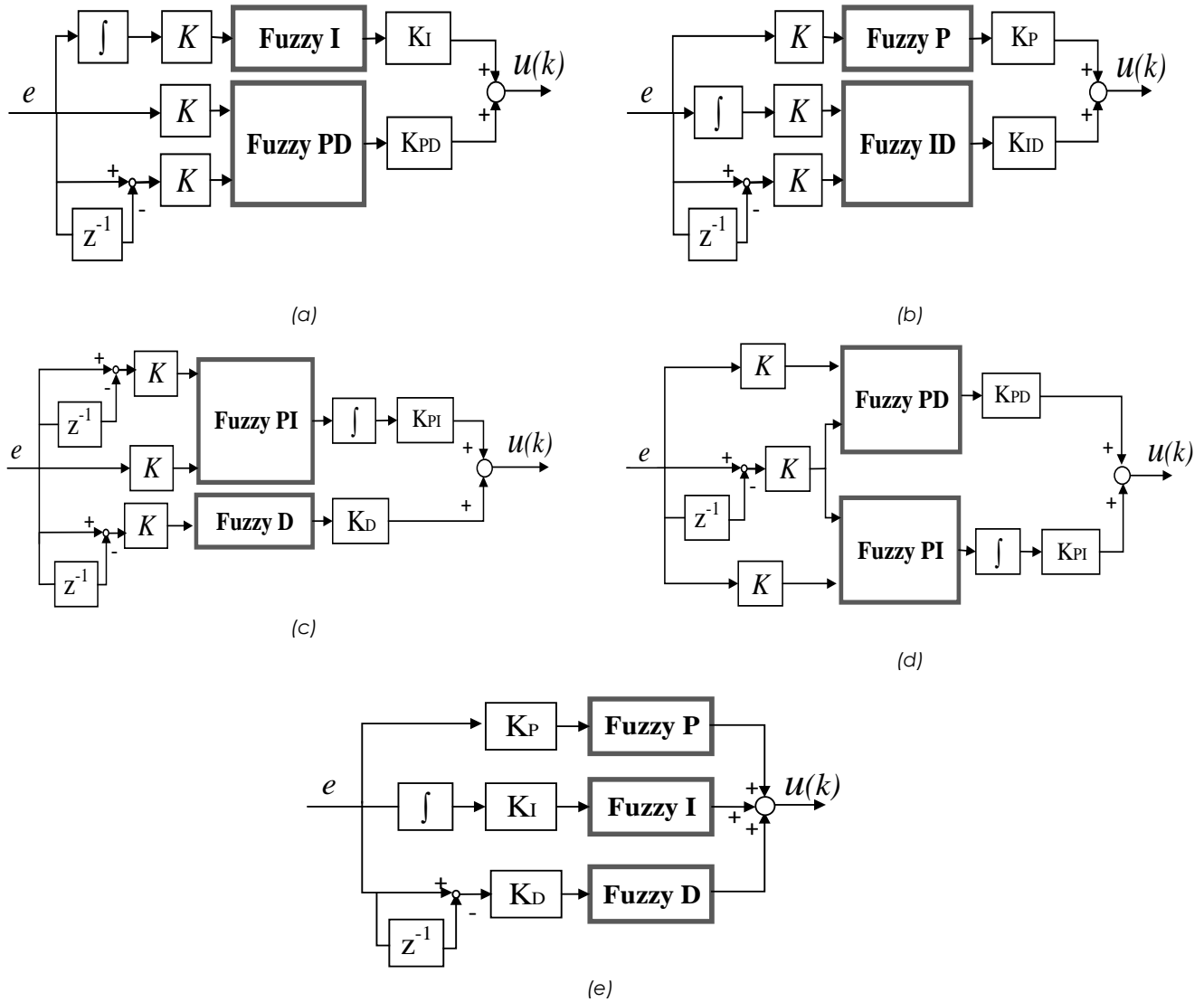
(a)

(b)

(c)

(d)

(e)

Figure 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 Dform

5.0 PROPOSED FUZZY PID CONTROLLER

The decomposed Fuzzy PID control structures presented in literature eliminate the complexity of the three-dimensional rule table. However the design 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, where the output of the first stage will become the input to the next stage). The proposed controller is decomposed into two Fuzzy control stages. The structure of the proposed controller is shown in Figure 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).

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

Where,

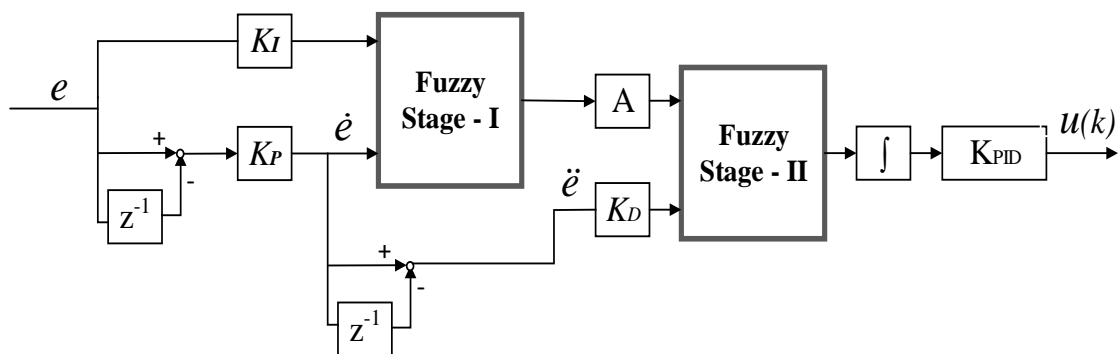$$G_P = K_P.A ; \quad G_I = K_I.A ; \quad G_D = K_D$$

Figure 4 Proposed cascade structured decomposed Fuzzy PID controller.

6.0 DISCUSSION

Various structures of the decomposed Fuzzy controllers found in the literaturehave been discussed inthein this paper.In general, these controllers can be classified into Fuzzy + Conventional type and Fuzzy + Fuzzy type decomposed Fuzzy PID controllers. Both structures have their own unique capabilities and drawbacks. There are designed to tackle specific problems for certain applications.

Apparently, multiple-input (more than two inputs) fuzzy control system suffers from difficulty in designing its rule table. The increasing number of input also will increase the number of tuning parameters, hence the complexity. The decomposed structure is proposed to overcome these problems.

The decomposed structure reduced the dimension rule table into two or one dimension. Most of the decomposed fuzzy controllers are in the structure of one single stage processing (parallel processing). In terms of control trouble-shooting and tuning, these type of structure is rather complex. The number of tuning parameters are also can still be considered as large.

Our proposed decomposed structure exhibits a cascaded fashion. The output of the first stage will become the input of the second stage. In terms of control trouble-shooting, this structure yields less complexity due to the cascaded arrangement. The parameters fine-tuning is also less complex though the number of tuning parameters is still large.

Another unique advantage and highlight of the proposed controller is the possibility to reduce the number of rules and tuning parameters by applying the signed distance method [25, 35]. By applying this method, the proposed controller will become SISO fuzzy system and the rules inference process can beapproximated as piecewise linear control surface [55].

7.0 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.

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