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A PLC-based modified-fuzzy controller for PWM-driven induction motor drive with constant V/Hz ratio control

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ABSTRACT

In this paper, a method to develop and design a fuzzy-hybrid control on an industrial controller to control speed of an induction motor and implementing a constant V/Hz ratio control is presented. Detailed discussions on the controller for a PWM-driven induction motor drive system, the system identification for the model transfer function, and the analysis on output responses and the associated manipulated variables are presented. The control objective is to provide an effective control action to sudden changes in reference speed and/or load torque. A switching type controller consisting of two control modes are devised: a PID-type fuzzy controller consisting of a PI-type and a PD-type fuzzy controller, and a conventional PID. At the early phase of the control action, the control task is handled by the PID-type fuzzy controller. At a later phase when the absolute of error is less than a threshold value, the input of integrator at the output side is no longer given by fuzzy action but fed by the incremental PID action. In term of control action, this is an enhanced proportional and derivative action when the actual value is closed to reference. Detailed evaluations of the controller's performance based on pre-defined performance indices under several conditions are presented. The findings demonstrate the ability of the control approach to provide a viable control solution in response to the different operating conditions and requirements.

1. Introduction

Motor drives are used in a very wide power range. In adjustable-speed drive applications the ranges of speed achievable is very important in applications such as controlling of a boiler feed-water pump. In all drives where the speed and position are controlled, a power electronic converter is needed as an interface between the input power and the motor. A controller is also needed to make the motor, through the power electronic converter, meet the drive requirements. Notably, the extensive automation in modern industries demand several strategies that have high reliability and robust to be introduced and one of the main requirements is the control technique used. The controller used in this work is a programmable logic controller (PLC) that proves to be very efficient and reliable in applications involving sequential control and the synchronization of processes and auxiliary elements in the manufacturing, chemical and process industries [1]. The availability of PLC with basic features like arithmetic operations and the improvement of graphical user interface (GUI) in programming and communication, promises the means to utilize the advantages of PLC in adjustable speed application [2]. Successful examples of utilizing PLCs in control as main controller are related in [3–9], while as an assistant device control is related in [10]. The application of PLC in industry as a monitoring and controlling a system with multi-tasking have been reported in [11–14].

The proportional, integral and derivative (PID) is by far the most dominating form of feedback in use today and is used in wide range of problems, see [15]. It is able to eliminate steady state error, which is implemented by the integral component and able to anticipate for the future that is operated by the derivative component [16]. The two types of tuning methods for this control are the classical and modern tuning methods, where the classical method is based on the experiment response while the modern method relies on process model. In real application, model of the process is usually quite complex, ill-define and sometimes it is not easy to produce. Therefore, the modern tuning method is more suitable when the process model is known. Fuzzy logic has been widely implemented in several areas such as in house hold appliances, transportation, etc. Fuzzy logic is suitable for controlling a system that has a complicated process model [17,18]. Designing of fuzzy logics, membership function and rules are usually subjective and no standard method in designing the input output gains [19]. Usually the fuzzy designers utilize the expert or experience of the human operation information.

Several efforts have been put to improve the controller performance including fuzzy logic. In relation to fuzzy logic, it

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can be seen as a PI, PD or PID controller in which the decision would be made by fuzzy algorithm. Hence, most of the improvement works are on tuning the parameter of the *P*, *I* or *D* either individually or simultaneously. Several previous work on improving the fuzzy logic controllers can be found in [8,19–25]. Li et al. [10] considered the problem of developing the input–output gain scheduling to improve the control resolution. An alternative way to increase the resolution of fuzzy controller on PLC has been conducted. Chung et al. [19] attempted to tune all three scaling factors using a single input fuzzy controller. There are quite a number of reports on tuning the change of error input gain and output gain based on peak observer, mathematical function driven by error and rate of error, respectively. These include Karasakal et al. [8], Qiao and Mizumoto [24] and Woo et al. [25].

There are quite a number of reports on the hybrid fuzzy-PID controller. These includes Mudi and Pal [22,23] and Guzelkaya et al. [20]. More specifically, Mudi and Pal [22,23] developed an approach to tune a PI and PD-type fuzzy controllers to output gain. In the design, an extra fuzzy logic controller performs as a controller to tune the output gain. A second fuzzy controller, with quite complex rules, is used to tune the output scaling factor and utilized the same input as main fuzzy controller i.e. error and change in error values. The proposed rules of the fuzzy parameter tuner were also able to provide self-tuning and anti-windup mechanism. Karasakal et al. [21], proposed a self-tuning for PID-fuzzy controller. A second fuzzy controller is employed to perform the self-tuning, and was based on the information of error and relative rate of error. A relative rate observer was utilized to indicate whether the system response was fast or slow. Based on that condition, the developed rules determined the scaling factor for the change in error input gain and PI-fuzzy output gain. Basically the proposed method tries to tune the *I* and *D* fuzzy-parameters keeping proportional parameter fixed, but it provides a gain to change the proportional parameter as well.

In addition to the above, there were a few reported works on attempting to improving fuzzy controller using PLC. For example, [8,21] discussed the implementation of gain scheduling and tuning with relative rate observer. A comparative analysis of PI and Fuzzy controllers was presented in [26]. It was a comprehensive comparison in a different situation including sudden change in reference and load. It was accounted that in some conditions fuzzy logic has better performance than PI, and vice versa. It was shown that for a large change in reference, fuzzy controlled gives faster response than a conventional controlled. In relation to insufficient resolution of fuzzy inference, the theoretical study shows that an inferior performance of fuzzy controlled process around a reference point is expected [10]. In real implementation, it can be caused by either the truncating process, rounding process or less word length.

Notably, there is substantial literature on control using hybrid-fuzzy controllers; however, there is only a few literature on induction motor speed control fed by variable-voltage variable-frequency (VVVF) using hybrid-fuzzy controller, examples in [12,13,27]. This work is similar to [12,13], but unique in terms of the controller used, i.e., a hybrid fuzzy-PID, and the control technique approached, i.e., VVVF with constant V/Hz ratio.

This paper's contribution is as follows: a design of a fuzzy control algorithm for a PLC-based fuzzy controller for an induction motor speed control (adjustable speed drive) at constant V/Hz ratio with the PLC-based fuzzy controller interfaced to the motor via a pulse-width-modulation (PWM) inverter.

The paper is organized as follows: Section 2 discusses the system layout of PLC-based fuzzy controller for PWM-driven induction motor drive. Section 3 summarizes the design of the proposed modified-fuzzy controller. Illustrative example on the system identification for the model transfer function is presented in Section 4. Section 5 discusses on the controller design and the implementation in PLC. The experimental results are presented in Section 6, while Section 7 gives the conclusion of this paper.

2. The system layout of PLC-based fuzzy controller

The plant consists of a PWM inverter, an induction motor and a load. The PWM inverter functions as an interface between the PLC and the induction motor. The personal computer (PC) acts as a terminal for developing and downloading the program including the fuzzy logic routines to PLC and human–machine-interface (HMI) design to HMI. The connection between PC and PLC is established via Ethernet TCP/IP. The system also has a forward/reverse contactor to accommodate bidirectional rotation for the motor. The physical system layout and the related electrical connection of the test rig is illustrated in Fig. 1.

The PLC is equipped with a digital input–output and an analog input–output module. The rated input voltage of the digital input is 24 V DC while for the digital output is 12–24 V DC. To control the low voltage forward/reverse relay contactors running at low voltage (24 V) that drive the magnetic contactors two digital output points are used. One channel of analog input and two channels of analog output are used where the input channel is to measure the analog voltage that represents the actual speed while one of the two analog outputs is to send the manipulated variable (u) to the variable speed drive and the other is to specify the load applied to the induction motor.

The PWM inverter constitutes the main component of a variable speed drive (VSD). The VSD requires a three-phase supply on its line side and produces sequences of three-phase PWM on its output side, and this is arranged to drive the 3-phase squirrel cage 240/115, 50 Hz, 175 W and 1395 rpm induction motor. The VSD is rated at 0.75 kW, 415 V line-to-line on its output load side and its frequency is controlled by a 0–10 V analog signal coming from the analog output module of the PLC. There is a linear relation between 0 and 10 V of analog signal to the PWM inverter and 0–50 Hz analog output from PWM inverter to the three phase induction motor. The modulation implemented on the PWM inverter is a sine pulse-width-modulation (PWM) that runs on

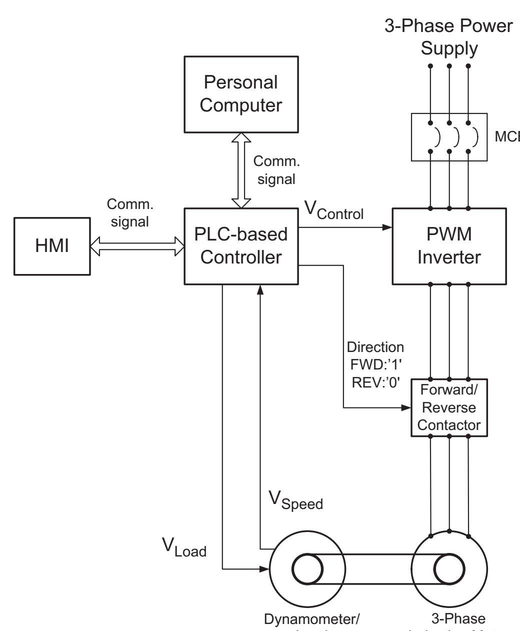

Fig. 1. Physical system layout with HMI, PLC, PWM inverter, induction motor and load.