

A new fuzzy self-tuning PD load frequency controller for micro-hydropower system

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Abstract. This paper presents a new approach for controlling the secondary load bank of a micro-hydropower system using a fuzzy self-tuning proportional-derivative (PD) controller. This technology is designed in order to optimize the micro-hydropower system in a resort island located in the South China Sea. Thus, this technology will be able to mitigate the diesel fuel consumption and cost of electricity supply on the island. The optimal hydropower generation for this system depends on the available stream flow at the potential sites. At low stream flow, both the micro-hydropower system and the currently installed diesel generators are required to feed the load. However, when the hydropower generation exceeds the load demand, the diesel generator is shut down. Meanwhile, the system frequency is controlled by a secondary load bank that absorbs the hydropower which exceeds the consumer demand. The fuzzy rules were designed to automatically tune the PD gains under dynamic frequency variations. Performances of the fuzzy self-tuning PD controller were compared with the conventional PD controller. The result of the controller implementation shows the viability of the proposed new controller in achieving a higher performance and more robust load frequency control than the conventional PD controller.

1. Introduction

Load frequency controller (LFC) is a very important component of an electrical power system's operation and control. The objective of a LFC is to regulate the voltage and frequency of the system to the specified nominal values, in case of fluctuations [1]. A well designed and operated power system must able to handle changes in the load and system disturbances. Furthermore, it should provide a high level of power quality while maintaining both voltage and frequency within acceptable limits.

Many investigations have been reported relating to load frequency controller. There are researchers proposed control strategies for LFC, based on classical linear control theory [2]. However, due to the inherent characteristics of the varying loads, the operating point of a power system varies continuously throughout a daily cycle. Therefore, a fixed controller may no longer be suitable under all operating conditions. Many advanced control methods utilizing soft computing approaches have been reported, such as Artificial neural network (ANN) [3], Genetic algorithms (GA) [4], Particle swarm optimization (PSO) [5], Fuzzy logic [6] and Bacterial foraging optimization algorithm (BFOA) [7]. These controllers have been extensively used in LFC and have shown to provide more robust control compared to classical control techniques. However, these methods require the system's plant model, which is very challenging to obtain for a large electrical power system.

The artificial intelligence controller also tends to be complex and specific to a particular installation, thus making them expensive to construct and difficult to maintain and reconfigure. Hence,



these particular types of controllers are not suitable to be implemented in micro-grid systems for remote areas that require low cost and easy-to-maintain controllers.

A new load frequency controller, based on fuzzy gain scheduling of PD controller is proposed in this paper. Fuzzy rules and reasoning has been utilized in order to determine the PD controller parameters. Hence, the controller has the capability to modify its parameters when the system dynamics or the disturbance characteristics vary. Furthermore, this method does not require a precise model of the system dynamics under control. In this system, a fast response secondary load system is required in order to control the frequency of the micro-grid, to allow the diesel generators to be shut down during periods of high stream flows. Therefore, the control strategy must be adaptive and robust.

2. Fuzzy self-tuning PD load frequency controller

In this work, a new fuzzy self-tuning PD controller has been implemented to achieve a higher performance of the discrete frequency regulator than the conventional PD controller. Typically, PD gains are determined by the Ziegler-Nichols method based on the transient response characteristics of a plant. This method may produce initial estimations of the PD gains. However, a fine-tuning of the PD gains is required to obtain the most optimal dynamic frequency control under various load conditions. There is a trade-off between the system performance and robustness with fixed PD gain. Therefore, a systematic real-time PD gain tuning is required in order to increase the performance of a fixed gain PD controller. To achieve the performance targets in dynamic responses, the PD gains are tuned as in equation (1) and equation (2).

$$K_p = K'_p + \int \Delta K_p \quad (1)$$

$$K_D = K'_D + \int \Delta K_D \quad (2)$$

where K'_p and K'_D are the initial estimations of the proportional and derivative gains, whereas ΔK_p and ΔK_D are the adjustments of the PD gains. The block diagram of the new fuzzy self-tuning controller design is shown in figure 1. The fuzzy self-tuning scheme uses error, e and rate of change in error, \dot{e} in making decisions for tuning the PD gains. The fuzzification, fuzzy rule base, max-min inference mechanism and defuzzification for tuning the PD gain adjustments ΔK_p and ΔK_D , are based on the Mamdani model.

2.1. Fuzzification

The error and derivative of error are fuzzified from the crisp values to fuzzy variables with seven linguistic variables: Zero (ZE), Positive Small (PS), Positive Medium (PM), Positive Big (PB), Negative Small (NS), Negative Medium (NM) and Negative Big (NB) with each linguistic variable having a fuzzy membership value.

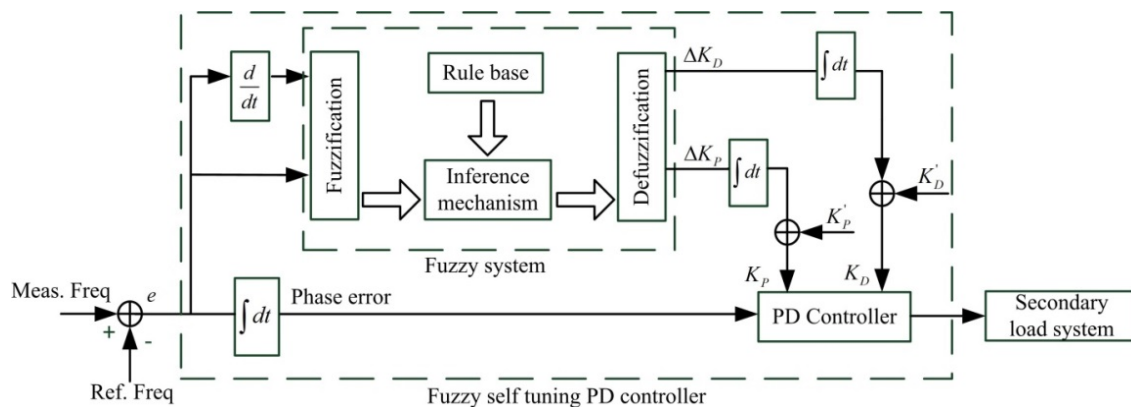


Figure 1. Fuzzy self-tuning PD discrete load frequency control architecture.

2.2. Inference mechanism

The inference mechanism takes the fuzzy input from the fuzzifier in form of membership values matrix, and uses the fuzzy rule base to make decisions on the fuzzy value of the output. The max-min inference mechanism is interpreted as follows:

For ΔK_P ,

Rule i : If e is A_e^i and \dot{e} is $A_{\dot{e}}^i$ then ΔK_P is B_P^i ; $i = 1, \dots, 49$.

For ΔK_D ,

Rule j : If e is A_e^j and \dot{e} is $A_{\dot{e}}^j$ then ΔK_D is B_D^j ; $j = 1, \dots, 49$.

where i and j are the indexes, A_e and $A_{\dot{e}}$ are the input linguistic variables of the error and the rate of change in error respectively, whereas B_P and B_D are the output linguistic variables of the proportional and derivative gain adjustments, respectively.

2.3. Defuzzification

The center of gravity method has been used to convert the fuzzy output of PD gain adjustments into a crisp value.

3. Performance analysis

The performance of the proposed controller was verified by considering two different scenarios: an additional 50 kW load at $t=1$ second, and a 50 kW load drop at $t=1$ second. The system's frequency output for both the new controller design and the conventional PD controller were compared and shown in figure 2.

To demonstrate the performance and robustness of the new proposed controller, performance indices such as overshoot, undershoot, settling time (at 0.05 %), steady state error (SSE), integral of the absolute error (IAE), integral of the squared error (ISE) and integral of time multiplied by the absolute error (ITAE) were considered in the analysis. The performance indices of both fuzzy self-tuning PD controller and the conventional PD controller are shown in table 1.

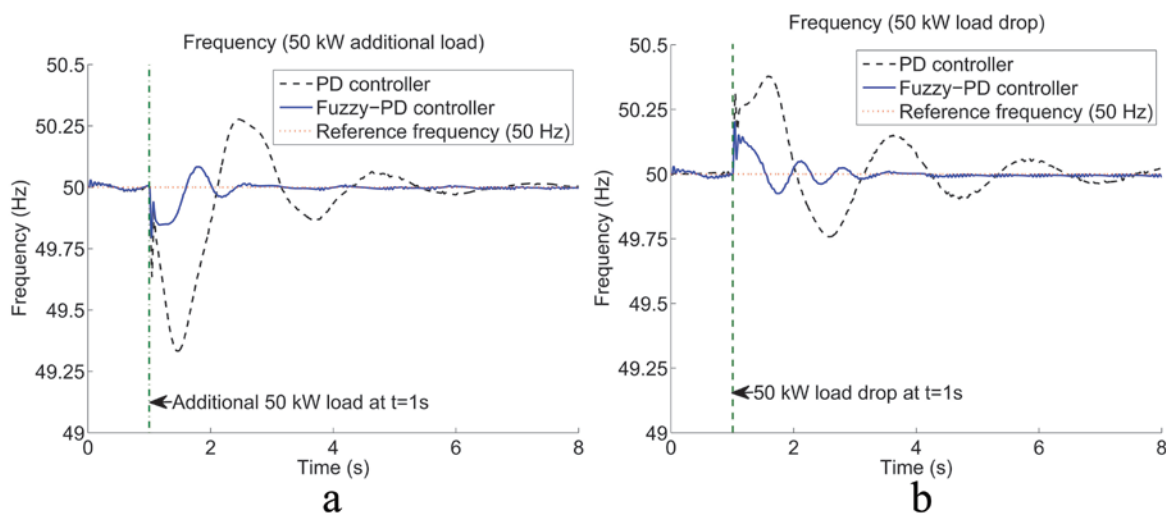


Figure 2. Frequency comparison between conventional PD and fuzzy-PD controller for a) 50 kW additional load b) 50 kW load drop.

Table 1. Performance indicators of the load frequency controllers.

Performance indicators	Conventional PD controller		Fuzzy self-tuning PD controller	
	50 kW additional load	50 kW load drop	50 kW additional load	50 kW load drop
Overshoot (%)	0.554	0.756	0.166	0.404
Undershoot (%)	1.333	0.484	0.409	0.150
Settling time (s)	5.132	6.316	1.299	1.545
SSE (Hz)	0.004	0.023	0.003	0.010
IAE	2.430	2.404	0.981	0.977
ISE	0.641	0.630	0.185	0.183
ITAE	9.583	9.487	3.811	3.815

4. Conclusion

A new fuzzy self-tuning PD control architecture was proposed in this paper in order to achieve the dynamic performance targets. The fuzzy rules were generated based on expert knowledge to efficiently tune the PD controller gains. The results of the new controller implementation on the system were compared with the PD controller without fuzzy self-tuning mechanism. It is observed that the fuzzy self-tuning mechanism considerably decreases the overshoot, settling time, SSE, IAE, ISE and ITAE in the frequency control.

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