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An innovative fuzzy logic frequency regulation strategy for two-area power systems

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ABSTRACT

Modern environmentally friendly power system designs offer several application benefits, but they also generate losses. In order for this structured power system to operate reliably, the total generation, total load demand, and system losses must be balanced. Changes in load demand disrupt both the real and reactive power balances. As a result, the system frequency and tie-line interchange power differ from their planned values. A large variance in system frequency can cause the system to crash. Multiple connected area systems use clever load frequency control techniques in this scenario to deliver dependable and high-quality frequency and tie-line power delivery. In this case, a freestanding hybrid power system is considered, with generated power and frequency intelligently managed. In addition to the unpredictability of the wind, frequent changes in the load profile can result in significant and damaging power variations. The output power of such renewable sources may fluctuate to the point where major frequency and voltage variations occur in the system. The fuzzy logic PID controller (FLPIDC) is an intelligent approach recently proposed to address the load frequency control (LFC) issue of an interconnected power system. Standard proportional integral derivative (PID) controllers operate each section of the system.

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1. INTRODUCTION

In developing countries, the use of renewable energy sources to make electricity has grown in recent years. As development moves faster, more people will need electricity, which makes the gap between supply and demand even bigger. Consequently, it is becoming increasingly difficult to satisfy the growing demand for electricity with conventional sources [1]. Natural sources of energy are fuel-free, environmentally favorable, and sustainable, but they are also unpredictable. To reliably power isolated loads, diesel systems are frequently combined with clean energy sources such as solar, wind, and small-scale and mini-hydro. To meet capacity requirements, a modest supply system is used to operate parallel diesel generator sets with synchronous electrical generators and sources of renewable energy [2].

Despite the minimal generation capability of grid-connected systems, especially in developing nations, many rural and remote areas around the globe [3]. If some of the locations have independent or distinct power systems to satisfy load demands, the supply-demand discrepancy can be reduced. Furthermore, wind power is expected to be economically appealing when wind speed at the targeted site is substantial for electricity generation and grid connection is difficult. This is especially common on islands and/or in remote places [4].

Furthermore, wind power is expected to be economically appealing from the grid. This is a common occurrence on islands or in rural areas. A hybrid wind-diesel system is very trustworthy since the small-scale source of energy acts as a buffer to absorb variations in wind speed and maintain the power constant [5]. This hybrid energy system must be expanded due to the increasing electricity demand in a remote village. Where there are multiple water courses, a micro hydro-producing unit is added in parallel. The design and mode of operation of the generation controller will have a substantial impact on the ultimate hybrid power system's capacity to satisfy consumer demand [6].

Hybrid power systems, for example, have very little capacity in contrast to conventional power systems in many countries. However, they are essential because they are the only source of electricity for populations in areas where conventional utility power is unavailable. Diesel generators are utilized in India for irrigation and mobile phone antennas [7]. A lot of industrial units also use diesel engines because they can't get power from the grid or because the grid isn't always on. As a result, many organizations, both public and private, are working on hybrid methods to make power generation more efficient while also getting carbon credits [8].

Due to the unpredictability of the wind and the rapid alterations in load requirements, huge and violent electrical outages may occur. Fluctuations in the output power of these renewable energy sources could cause significant frequency and voltage fluctuations in the grid [9]. A suitable control strategy is therefore required to maintain the scheduled frequency. Essential for sustaining frequency oscillations and keeping system frequency within a reasonable range is an effective controller. If the frequency cannot be kept within an acceptable range, the system could become unstable. Therefore, a reliable frequency controller is anxiously anticipated [10].

2. PROPOSED TECHNIQUE

In order for an electric power system to function, both frequency and voltage have to be at their prescribed levels. Essential for maintaining these constant power system parameters is the control system. The majority of LFC speed governors employ PI and PID controllers. To meet the needs of contemporary applications, it would be preferable to increase the capacity of PID controllers. The primary impetus for the progression of PID controller construction techniques is the significant impact of performance enhancement. This paper therefore proposes a novel multistage fuzzy logic method for fine-tuning the PID controller's parameters in order to improve system performance.

In remote, isolated locations with significant wind speed for electricity generation, the isolated hybrid system uses multiple energy sources to produce electricity [11]. In an autonomous system, it is more difficult to control the frequency. Article implements an isolated hybrid power system with an innovative smart multistage fuzzy logic PID controller to control frequency deviations [12]. In an autonomous system, frequency control is more problematic. In the proposed article, the LFC of a standalone hybrid power system is governed by a unique, intelligent fuzzy logic PID controller with different stages. The proposed controller maintains the hybrid power system's enhanced dynamic performance while modulating frequency and generated power significantly better than previous controllers [13].

From the Figure 1 in two are energy systems, the incremental tie line power is represented as (1).

$$\Delta Ptie12(s) = [\frac{2\pi Tp12}{s}](\Delta F1(s) - \Delta F2(s)) \tag{1}$$

Where $(\Delta F1(s)$ & $.\Delta F2\ (s)$ are system frequency deviations. The tie line current flow represented as (2).

$$I12(s) = \frac{(V1<\theta)-(V2<\theta)}{j(X12)} \tag{2}$$

The tie line current flow with controller represented as (3).

$$I12(s) = \frac{(V1<\theta)-(V2<\theta)}{j[(X12)-Xcontr} \tag{3}$$

Where X12 is reactance of the tie line power. Complex power of incremental tie line represented as (4) and (5).

$$P12 + jQ12 = S12 \tag{4}$$

$$P12 + jQ12 = V1 * I12 \tag{5}$$

Tie line power flow can represent as (6).

$$Ptie12 = \frac{V1*V2}{j[(X12)-Xcontr}\sin(\theta 1-\theta 2) \tag{6}$$

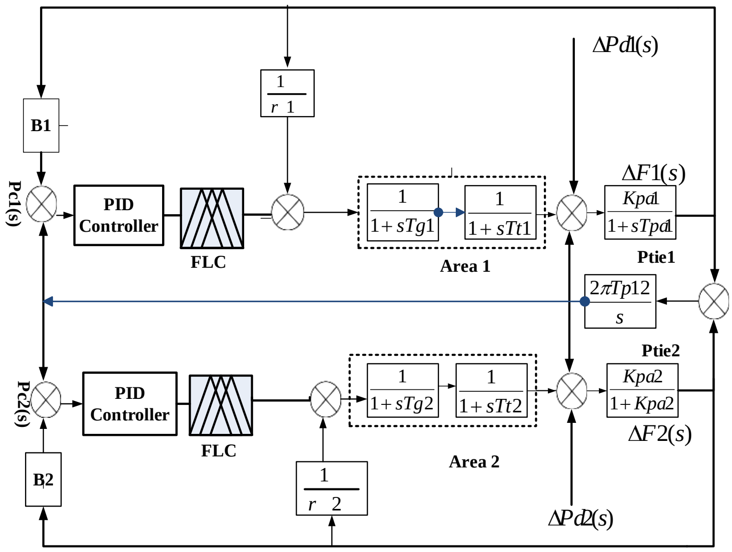

Figure 1. Hybrid power system LFC multi-stage FLPIDC block diagram

3. DESIGN OF MULTI STAGE FLPID CONTROLLER

3.1. Introduction

A FLC's fundamental configuration consists of four primary components [14], [15]: fuzzification, interface mechanism, knowledge base, and defuzzification. The initial process is fuzzification, which includes shifting the input and output ranges of the FLC into their respective universes of conversation. The second step involves separating these inputs into linguistic variables. The fuzzification module's parameters depend on the structure of the membership functions (MF) [16].

FLC's interface mechanism plays a crucial function. In this stage, the membership values obtained in the fuzzification step are merged to determine the firing strength of each rule. Using a set of language control rules, each rule specifies the domain experts' control objective and control policy. Next, based on the firing strength, the subsequent portion of each qualified rule is formed [17].

A FLC's knowledge base consists of a database. The primary goal of the database is to supply the essential information for the fuzzification module, the inference engine, and the de-fuzzification module to operate effectively [18]. The defuzzification module executes the subsequent operations: i) Transforms the updated control output values into a control action that is not fuzzy; and ii) Executes a de-normalization of the output that translates the value range of fuzzy sets to the physical domain [18].

3.2. Fuzzy logic controller to power system

3.2.1. Tuning of fuzzy logic controller

This designed controller, which relies on Greg Viot's fuzzy cruise controller, is used to maintain an uninterrupted organized power system at specified frequency levels [19], [20]. Input variables (E, ΔE) and output make up FLC in the multistage FLPIDC proposed in Figure 2 [21]. The pre-compensator of the multistage FLPID controller outputs a control signal that is (7).

$$Fpid = KpE + Ki\int E + Kd\frac{\Delta E}{\Delta t} \tag{7}$$

The given scheme's control signal is (8).

$$\mathrm{Mo/p} = F(\mathrm{pid}) \tag{8}$$

Where Kp- proportional gain, Ki- integral gain, and Kd – differential gain.

Using the fuzzy toolkit, the multistage FLPIDC file is generated. The FIS editor for the fuzzy logic controller file is created. The fuzzy inference system (FIS) editor displays relevant information regarding the multi-stage FLPIDC. FLC's rules are added by the rule editor [22]. With E, delE, and F. (S) as inputs and F. (S) as output, the MATLAB software is used to develop the FIS editor. In this FIS file, the range of input 1 E is assumed to be between -0.1 and 0.1, the range of input 2 del E is assumed to be between -1.0 and 1.0, and the range of output F. (S) is assumed to be between -1 and 1.5. In addition, seven principles (listed in Table 1) have been considered in the FIS editor [22].

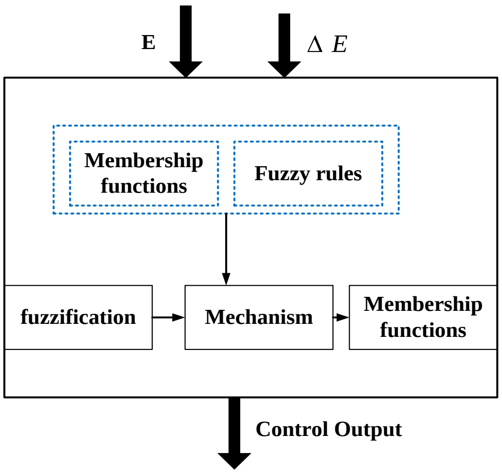

Figure 2. Block diagram representation of fuzzy controller

Table 1. Fuzzy rules

E ↓ delE →	NegL	NegM	NegS	Z	PosS	PosM	PosL
NegL	PosL	PosL	PosL	PosM	PosM	PosS	Z
NegM	PL	PosM	PosM	PosM	PosS	Z	PosS
NegS	PosM	PosM	PosS	PosS	Z	NegS	NegM
Z	PosL	PosM	PosS	Z	NegS	NegM	NegL
PosS	PosM	PosS	Z	NegS	NegS	NegM	NegM
PosM	PS	Z	NegS	NegM	NegM	NegM	NegM
PosL	Z	NegS	NegM	NegM	NegL	NegL	NegL

NegL -negative large; NegM-negative medium; NegS-negative small; PosL-positive large; PosM-positive medium; PosS- positive small; Z- zero

3.2.2. Tuning of PID gain values in fuzzy logic controller

The FLC is an example of a nonlinear controller that works well in both linear and nonlinear situations. FLC is demonstrated to be a linear PID controller under equilibrium or steady-state conditions. So, the overall tuning of the FLC can be accomplished to acquire the desired or ideal response by adjusting the FLC parameters as the linear equivalent of a traditional PID controller. The standard PID stabilizer's parameters serve as a starting point for fine-tuning the FLC. Hence, in FLC, gain values should be computed at the point of equilibrium, where they should be proportionate to the input E without a controller [23].
Gain values of PID in FLC represented as (9)-(11).

$$Kp = {}^{Gp * H}\!/_{2A(m-1)} \tag{9}$$

$$Ki = {}^{Gi * H}\!/_{2A(m-1)} \tag{10}$$

$$Kd = {}^{Gd * H}\!/_{2A(m-1)} \tag{11}$$

Where Gp, Gi, Gd are gain values of PID controller; m is number memory functions; and A is distance between the adjacent members to MFs

3.3. Defuzzification

When the output of a system is not perfect, it is sometimes easier to come to a clear answer if the output is modeled as a single scalar variable. The reverse of "fuzzification, defuzzification," lowers a fuzzy set to a single, distinct value. The centroid methodology is also known as the area method or center-of-gravity method [24].

Figure 3 illustrates the analytical structure of the proposed fuzzy controller, which takes into account symmetrical triangular MF partitioned uniformly within the shared Universe of Discourse for the control variables. [-1, +1] is chosen as the UOD of the input and output variables. Only expressions in the UOD range are derived [25]. The membership functions are positioned within the overlap area. In fuzzy sets of inputs and outputs, all MF members are of the same type. The centroid DE fuzzifier is used to obtain the final crisp output.

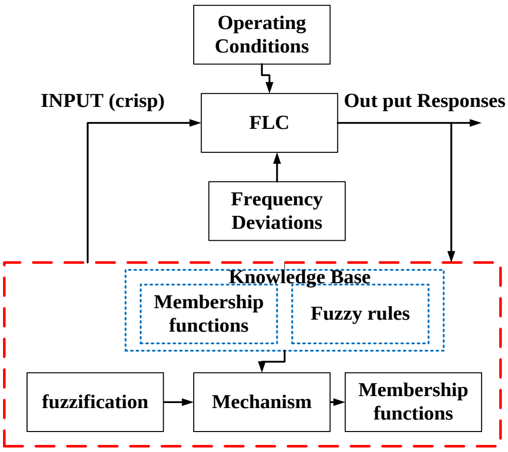

Figure 3. Analytical structure of FLC scheme

4. RESULTS AND DISCUSSION

By employing the parameters of the recommended multi-stage FLPIDC for LFC, a number of load disturbances are simulated on the Simulink model of a hybrid power system. The load frequency control for the two-area system uses the self-tuning FLPIDC to maintain the system frequency range, two-area powers, and tie- line powers at their specified levels.

In simulation experiments, it is assumed that the system will experience input power and load fluctuations of 0.01 in pu, 0.02 in pu, 0.03 in pu, and 0.05 in pu, respectively. Using various schemes, Figure 4 through 7 illustrate the responses of the PID method to variations in frequency, $\Delta Pm1$, $\Delta Pm2$, and tie-line power.

- Case 1: Two area control without scheme

The Figure 4 illustrates the unregulated frequencies and powers of two area systems. In the absence of a control technique, the power system is unable to maintain stability at a capacity of 1,000MVA. Consequently, in a multi-area system, the amplitude of frequency and voltage fluctuations is amplified when the load is deactivated or undergoing alterations.

- Case 2: Two area control with PID technique

Figure 5 illustrates the implementation of load frequency management through the utilization of a proportional-integral-derivative (PID) approach. At a load of 1000 MVA, the frequency of the two area systems reached a stable state within a time interval of 5.8 to 5.9 seconds, while the powers of the systems stabilized within a time interval of 5.62 to 5.79 seconds, respectively. At a time of 05.82 seconds, equilibrium was achieved in the voltage of the tie-line.

- Case 3: Two area control with FO-PID technique

The load frequency control using the FO-PID scheme is illustrated in Figure 6. This scheme ensures the stabilization of the frequency of two area systems, operating at a load of 1000 MVA, within the time interval of 5.79 to 5.91 seconds. Similarly, the voltages of both systems stabilize within the time interval of 5.69 to 5.71 seconds. The voltage on the tie-line reached a stable state at a time of 5.78 seconds.

- Case 4. Two area control with proposed technique (FLPIDC)

Figure 7 illustrates the load frequency control using a FLPIDC scheme. In this scheme, the frequencies of two-area systems with a load of 0.01 p.u. reached a settled state in 2.934 and 2.976 seconds, while the powers settled in 3.682 and 4.751 seconds, respectively. The intensity of the tie-line reached a stable state at a time of 3.931 seconds. Hence, the FLPIDC approach exhibits more efficiency.

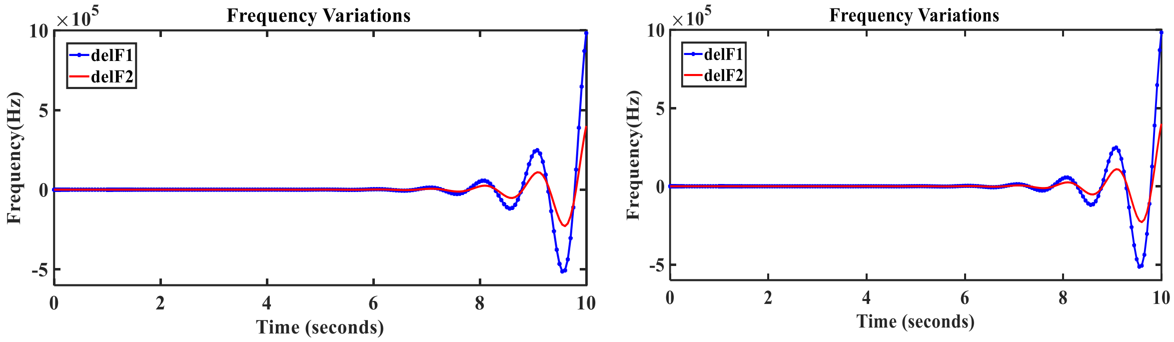

Figure 4. Frequency and power variations without PID scheme in two area system

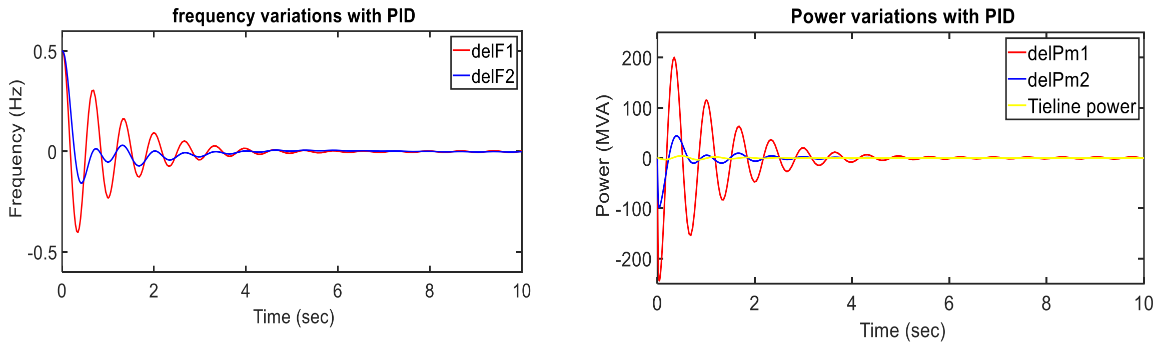

Figure 5. Frequency and power variations with PID scheme in two area system

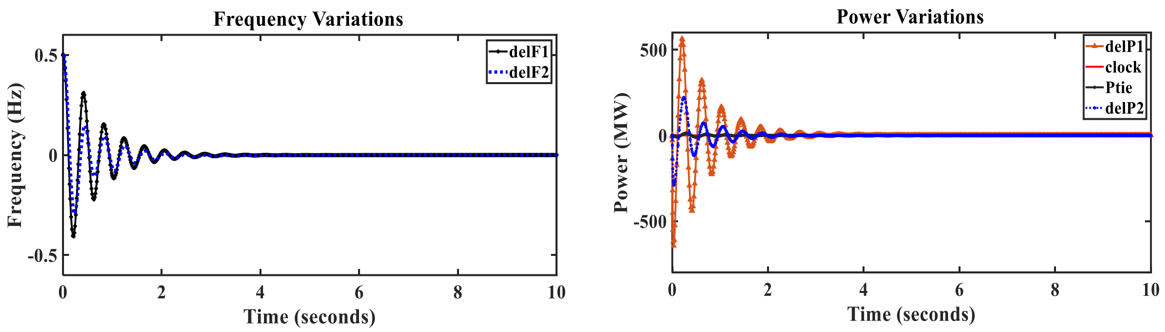

Figure 6. Frequency and power variations with FO-PID scheme in two area system

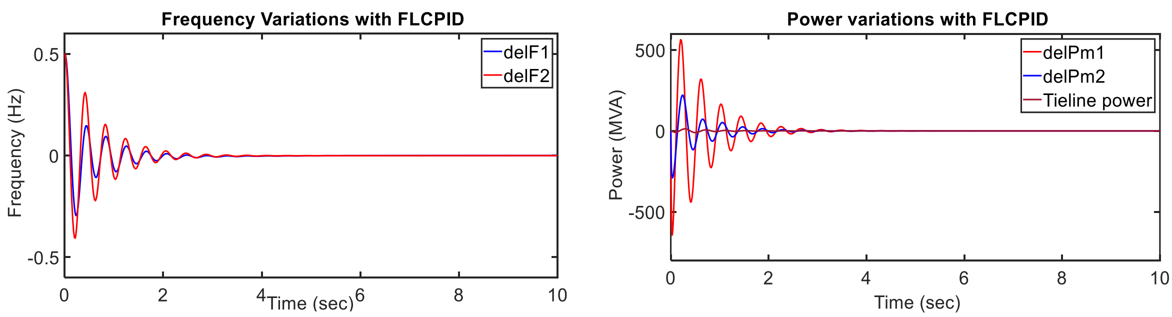

Figure 7. Frequency and power variations with FLPIDC scheme in two area system

5. CONCLUSION

The FLPIDC technique is developed for LFC of a two-area system, and various load disturbances are investigated. At larger load disturbances, the proposed FLPIDC is essential because it reduces dynamic response deviations and restores stable operation. The proposed controller demonstrates its superiority, provides dependable control, and maintains the system's dependability in the face of a variety of burdens and disturbances.

The suggested method has been changed to meet the goals of the design. It is now more lasting and can adapt to changes in the system's most important parts. The provided control structure is very helpful for LFC jobs and other difficult control uses. Also, the suggested control method has a lot of good things about it, like a faster response time, a simple design, enough freedom, and more accurate set-point tracking with less deviation.

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