Uluslararası İleri Doğa Bilimleri ve Mühendislik Araştırmaları Dergisi
Sayı 7, S. 40-46, 9, 2023
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Araştırma Makalesi

IJANSER
https://as-proceeding.com/index.php/ijanser
ISSN: 2980-0811

International Journal of Advanced Natural Sciences and Engineering Researches
Volume 7, pp. 40-46, 9, 2023
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Research Article

Implementation of Load Frequency Control Using Fuzzy Logic Controller in an Interconnected Power System

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(Received: 20 September 2023, Accepted: 05 October 2023)

(3rd International Conference on Innovative Academic Studies ICIAS 2023, September 26-28, 2023)

ATIF/REFERENCE: Kumar, S. V., Thamizhazhagan, P., Suman, M. & Periyazhagar, D. (2023). Implementation of Load Frequency Control Using Fuzzy Logic Controller in an Interconnected Power System. *International Journal of Advanced Natural Sciences and Engineering Researches*, 7(9), 40-46.

Abstract – Due to increased electrical system interconnection, load and power flow through tie-lines are dynamically changing. Thus, system frequency and tie-line power flows must be controlled reliably. Fuzzy logic controllers can provide resilient control instead of proportional, integral, and integral derivative controllers. Because conventional controllers have fixed gain levels, load changes do not effect performance. Load changes with time, while typical controller gain settings remain constant. Several more ways have been proposed in our effort to address typical controller weaknesses. Fuzzy logic basis controllers are being tested for load frequency control. The appropriate rules are implemented differently based on load variation to reduce errors. The error fluctuation is kept below the specified amount. The Sugeno type fuzzy inference system is ideal for seamlessly interpolating linear gains throughout the input space as a non-linear system moves around its operational region. Fuzzy logic controllers use triangular membership to create rule bases. This is because the triangle membership function makes rule bases easier than other membership functions. The results of comparing controller performance for different inputs for the identical two-area power system are below. Based on the data, the proposed fuzzy logic controller performs better.The proposed controller requires fewer training patterns than a neural network-based adaptive method, saving training time. This study investigates load frequency control's dynamic response using MATLAB Simulink.

Keywords –Fuzzy logic Controller, Load Frequency Controller, Matlab, Sugeno type fuzzy and PID Controller

I. Introduction

This document represents a template for ICIAS. Several applications in academia and industry concentrate on straightforward control algorithms with the goal of managing the ever-increasing complexity of regulated processes and systems. The technique that is used to develop the controller ought to permit complete control surface changeability. In practise, it is not uncommon to encounter complicated time-variant systems that include delays, nonlinearities, and dynamics that are not well defined.

Therefore, control methods that are based on linear system theory need to simplify and linearize nonlinear systems before they can be used, but these methods cannot guarantee good performance.

It is usual practise to design nonlinear controllers in order to provide satisfactory control of nonlinear systems. Constructing nonlinear controllers is difficult since there is not a general structure to work from. In addition, the majority of linear and nonlinear control methods developed in the past 30 years are predicated on in-depth mathematical models of the systems they are applied to [1].

Standard control approaches are unable to explain the majority of managed processes and systems because of the increasing complexity of these processes and systems. The technique that is used to develop the controller ought to permit complete control surface changeability. As a result of the fact that the majority of these systems cannot be defined by conventional mathematical relations, model-based design approaches might not be applicable. The attractiveness of FLCs can be attributed to the fact that they are founded on the theory of fuzzy logic and use approximate reasoning to model human decision-making.

Because knowledge is transmitted by norms that are both intuitive and verbal, specialists are able to comprehend FLC behaviour. FLCs, in contrast to linear and nonlinear control theory, are not mathematical models; rather, they are utilised to solve problems that arise in settings that are uncertain, ambiguous, and highly nonlinear. Since its introduction, FLCs have been utilised successfully in the fields of insurance and robotics. PID controllers used in conventional systems can benefit from fuzzy logic's artificial intelligence. Fuzzy PID controllers are able to automatically fine-tune themselves and adapt on the fly to uncertain, nonlinear, and time-varying systems. Industrial applications can take use of the many benefits offered by fuzzy PID controllers.

Electrical networks that are connected to one another ensure that operations are both safe and cost-effective. Automatic generation controllers, often known as AGCs, are responsible for ensuring that the supply of electricity meets demand. Each of the control regions that make up the linked power system is made up of one or more power utility companies. sufficient generation in each connected location to satisfy the load demand from customers.

In our paper, we make use of FLC. By placing a pole near the origin, this controller is able to limit the amount of steady-state error. Controllers have the ability to control the load on the system, which is never constant. Uncontrolled instances exhibit a greater degree of oscillation and negative overshoot, in contrast, the dynamic responses of PID and the suggested work are superior to those of conventional controllers.

A. Research background

In the present setup, load flow control is handled by traditional controllers like PID. The system's responsiveness to transients benefits from this enhancement. When compared to other controllers, PID controllers provide a higher degree of stability. During steady state, the PID controller minimises the error with almost minimal overshoot. Load frequency control, or LFC, refers to the challenge of managing the actual power output of producing units in response to variations in system frequency and tie-line power interchange while maintaining below predetermined limits.To keep the system from deviating too far from its intended stability, the LFC aims to create zero steady-state errors of frequency and tie-line exchange variations, high damping of frequency oscillations, and reduced overshoot of the disturbance.

The electricity grid is typically divided into control areas, with one or more power utility companies responsible for each control area.

a generation supply in each interconnected region adequate to meet the load demands of its clients. In previous works, numerous authors have used PI and PID controllers to successfully achieve the aforementioned aims. Here, the PID-tune controller is used to provide better frequency responses. In order to reduce steady-state error, this type of controller is used in power systems. The system load is never constant when using this controller, however it can be controlled. Negative overshoot can be observed when the uncontrolled situation exhibits more oscillation, yet the presented work result provides superior performances of dynamic responses compared to the conventional type of controller PID [2].

II. LOAD FREQUENCY CONTROL AND MODELING

If the system is linked to different loads in a power system, the frequency and speed of the system, as well as the characteristics of the governor, will change as the load changes. If a system doesn't need to keep a steady frequency, the person in charge of the system doesn't have to make any changes to how the generator is set. But if it's important to keep the same frequency, the user can change the governor's characteristic whenever it's necessary to change the turbine's speed. When there is a change in load that is handled by two generating stations that are running in parallel, the amount of complexity of the system goes up.

Here's an example of how the work could be split between two computers: Let's say that two power plants are connected to each other by a tie line. This type of control is called "Flat Frequency control," and it happens when the load changes at either A or B and only the generation at A needs to change to keep the frequency steady.

The other way the load could be shared is if both A and B controlled their own generations to keep the frequency from changing too much. Parallel frequency regulation is the name for this type of control. The third option is that the generator serving a certain area will change its output to match the change in frequency in that area. This way, the load on the tie-line won't move. This page talks about a method called "flat tie-line loading control." In the Selective Frequency control method, each system in a group is responsible for handling changes in load on its own system and does not help other systems in the group with changes that go beyond what it can handle.

In tie-line load-bias control, the frequency is controlled by all of the power systems that are linked to each other in the interconnection. This is true no matter which power system changed the frequency first. As part of the selective frequency control, the equipment includes a master load frequency driver and a tie line recorder that measures the power going into the tie. The error signal is amplified, mixed, and changed so that the real power command signal PV can be made. This signal is then sent to the prime mover to ask it to increase the force. The prime mover is responsible for changing the generator's output by an amount equal to PG. This will cause f and Ptie to change by an amount that is within the limit that was set. Before you can start to analyse the control system, you have to build a mathematical model of the many parts and control system methods it uses.

A. Load Frequency Control

The difficulty of managing the real power output of producing units in response to variations in system frequency and tie-line power interchange while remaining within set limitations is referred to as load frequency control, abbreviated as LFC. The goals of the LFC are to achieve zero steady-state errors of frequency and tie-line exchange fluctuations, high damping of frequency oscillations, and reduced overshoot of the disturbance, so that the system does not deviate too far from the stability for which it was designed. In general, the interconnected power system is divided into control areas, with each control area containing one or more utility companies. Each connected area must have sufficient generating capacity to meet the load demand of its customers. Load frequency control, also known as LFC, is a crucial component of large-scale, interconnected electric power systems. Its objective is to keep the system frequency and inter-area tie power as close as feasible to their scheduled values.

The mechanical power that is supplied into the generators controls the frequency of the electrical power output by the generators. This aids in ensuring that the intended power exchange between the various locations occurs. A properly constructed and operated power system must be able to cope with load fluctuations and system disruptions. Additionally, it must be able to provide an acceptable level of power quality while maintaining acceptable voltage and frequency. Academics have developed a variety of control algorithms for load frequency regulation in electric power networks over the span of the last few decades. This extensive research is required because LFC is a crucial aspect of the operation of power systems. This operation's primary objective is to regulate the output power of each generator to predetermined levels while maintaining frequency variations within predetermined limits. This extensive research is required due to this circumstance.

B. LFC in two area power system:

Governor-turbine systems are envisaged in each area with one comparable Generator. Control signals from controllers The work adapts a two-area model (Figure.2). Many generators are internally connected and swing together. Generator turbines have similar response characteristics. A coherent group of generators. The LFC loop can represent the entire system and be called the control group. Real tie line power during normal operation for a two-area system is

$$P_{12}=\frac{|E1||E2|}{X12}\sin\zeta_{12}$$

Where $X_{12}=X_1+X_{tie}+X_2$ and $\zeta_{12}=\zeta_1-\zeta_2$

For a small deviation in the tie-line flow

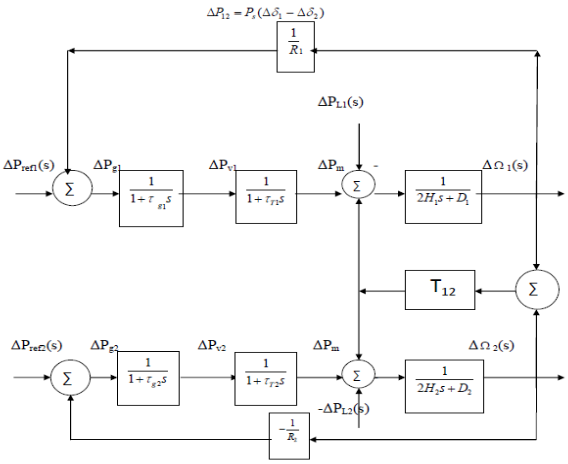

Fig 1. Two area system with primary loop LFC

Table 1. Example of a table

The plant for a power system with a non-reheated turbine consists of three parts:

• Governor with dynamics:

$$G_g(s)= 1/(1+TGs)$$

• Turbine with dynamics:

$$Gt(s)=1/(1+TTs)$$

• Load and machine with dynamics:

$$Gp(s)=Kp/(TPs+1)$$

Now the open-loop transfer function without droop characteristic for load frequency control is

$$P = GpGtGg=Kp/(TPs+1)(TTs+1)(TGs+1)$$

III. FUZZY LOGIC CONTROL

Results should be clear and concise. The most important features and trends in the results should be described but should not interpreted in detail.

The idea behind fuzzy controls is straightforward. Input, processing, and output are the stages that make up their structure[3]. The input stage converts inputs from sensors and other sources, such as switches, thumbwheels, and the like, into membership functions and truth values. During the processing stage, each rule is put into action, a result is generated, and the results are combined. In the final phase, which is called the output step, the combined result is converted into a control output value.

The membership functions that are used are typically triangular, but occasionally trapezoidal and bell curves are used instead. It is more important to consider the amount of curves as well as their arrangement. In fuzzy language, the "universe of discourse" of input values can be encapsulated by anywhere from three to seven curves. As was stated, the processing stage makes use of IF-THEN logic rules, in which the "antecedent" is represented by the IF and the "consequent" is represented by the THEN. The rules for fuzzy controls can often number in the dozens.

Three items are needed to set up the fuzzy system:

1. Define fuzzy sets (Membership Functions).
2. Set up the fuzzy inference system (rule base).
3. Defuzzifier.

A. Load Frequency Control Using Fuzzy Logic Controller

The implementation of the Load Frequency Control, which is the key emphasis of the project, is carried out with the help of the Fuzzy Logic Controller, which is used in order to carry out the implementation [4]. The membership function that is being adopted to take the frequency constant uses the number seven as its parameter in this iteration.

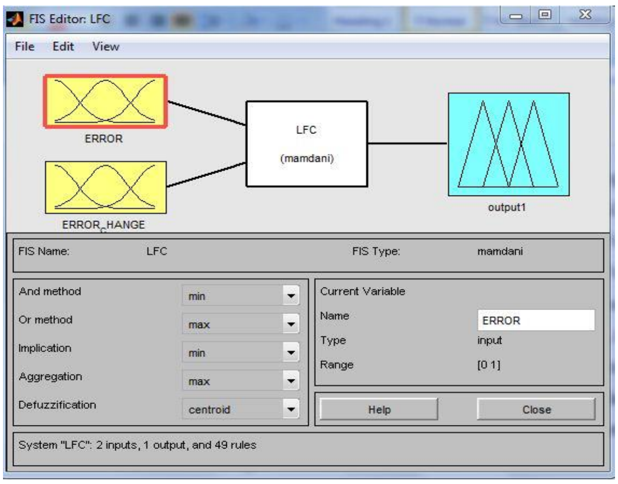

Fig 2. Inputs to the Fuzzy Editor

The values that make up these categories are as follows: a large negative (LN), a medium negative (MN), a small negative (SN), a very small (VS), a small positive (SP), a medium positive (MP), and a large positive (LP). These membership functions will provide a clear picture of how the Fuzzy can function in a variety of different ways that are not typical of a Small or Big in comparison to those methods [6].

These membership functions are brought into the Fuzzy Editor, which is the component of the software that is responsible for taking in the values that are inputted. The Fuzzy Inputs field accepts entries for the parameters Error (E) and Change in error (E), both of which are related to the error value.

IV. COMPARISON BETWEEN PID CONTROLLED AND FUZZY CONTROLLED LOAD FREQUENCY CONTROL

In order to solve the problem, we need to take into account an ideal power system with ideal parameters, which is the same thing as an ideal system with parameters that are the same as other ideal systems. If we have an interconnected system with parameters that are all the same, then the generators will be able to move in unison, and we will be able to represent them all with the same value for f. As a result of this, it is usual practise to allow the model of the ALFC loop reflect the entire "area," which, in a literal sense, can encompass an entire power system. When we talk about multi-area dynamics, we mean those that occur when this area is connected to the areas around it by tie lines[5].

When the results obtained by both controllers are compared, it is obvious that the fuzzy controlled controller has a better performance in terms of both settling time and change in frequency (F). When compared to other pairs of controllers, such as PD and PI, the PID-controlled LFC has a number of significant advantages, including improved stability and a quicker time to settle. The stability margin of this PID controller is quite low, and its peak overshoot is quite considerable.

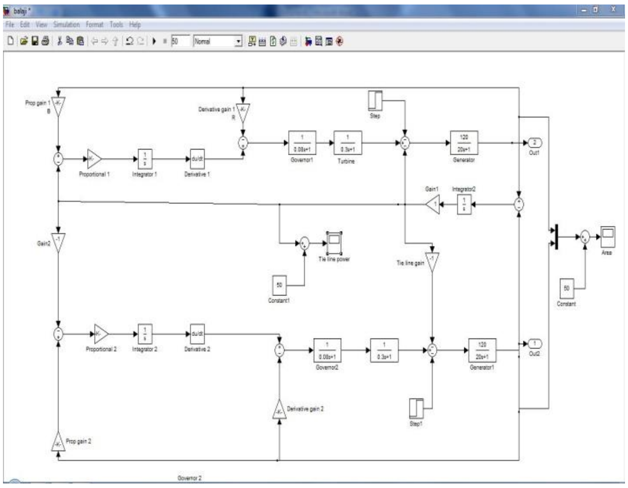

Fig. 3 Simulation of PID Controller

In the above matlab simulink, the two areas identical system with a similar gain values are interconnected together with help of tie line gain, which will help to share the load whenever it is needed. When the particular system exceeds the maximum demand then the tie line comes into action which will create load sharing between the load center's thus reducing the outages.

It is clear that the system settles but the only drawback is that it takes more time to settle, and the frequency deviation is also more which is not advisable. So, a new controller should be given so as to generate the required waveform. In our proposed system a fuzzy controller implemented and the same simulation is generated and the outputs are obtained.

A. COMPARISON

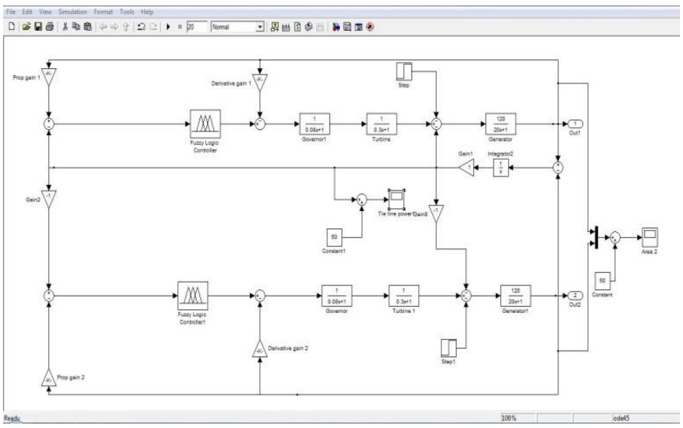

Fig. 4 Fuzzy Based Controller

The fuzzy rule is given on the bases of implementing the fuzzy rule set that is mentioned in the Fuzzy Controller chapter. The fuzzy rules are thus stored as .fis files and they should be saved in the current folder of the matlab software. On simulating the above simulation which has an identical system interconnected with help of tie line, the following output is generated.

Table. 1 Comparison of controllers

Type of Controller	Change in Frequency(ΔF) Hertz	Settling Time (Ts) Sec	Overshoot	Overall Performance
PID Controller	47.35	34	Normal	Nominal
Fuzzy Controller	48.25	18	Decreases	Excellent

On analyzing the obtained output it is clear that the frequency change (ΔF) as well as the settling time are reduced and seems to match the required parameter. The tie line output will give a very small variation in frequency that shows that the load is being shared between the two systems.

B. SIMULATIONS AND RESULTS

The results that is obtained by simulating the above simulations clearly explains that the PID controller takes more time to settle the oscillations and it also reduces the peak overshoot that is created by changing load system. The Frequency change (Δf) which also has a direct impact on system performance is also increased.

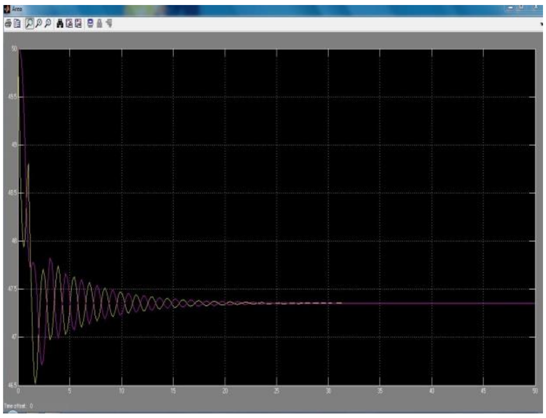

Fig. 5 Waveform for a two area system

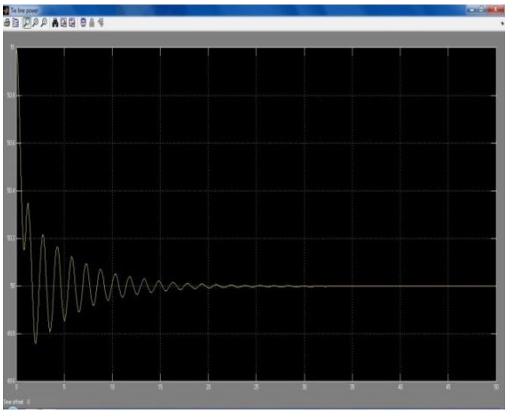

Fig. 6 Waveform for the tie line power interconnection.

The tie line output which shows a zero change in frequency(ΔF=0), clearly implies that there is interconnected between the system which also tells that the system frequency change is beyond the permissible values.

The proposed Fuzzy system is implemented as planned and their outputs are also analyzed. It gives the perfect and expected output of reduced settling time and Frequency change (Δf).

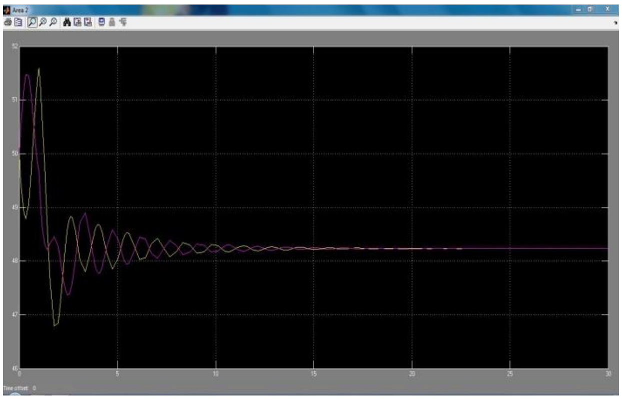

Fig.7 Fuzzy Based Load Frequency Controlled Simulation

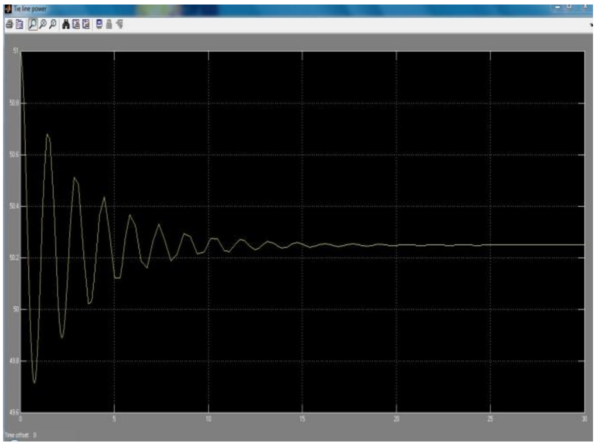

Fig.8 Tie line power

This simulation shows that the change in frequency is very low when compared to PID based LFC. The settling time is also low when compared to PID. So our project will increase the performance and efficiency of the power system.So it is advisable to implement our Fuzzy based Controller in practical and replace the existing PID controller.

V. CONCLUSION

The purpose of this research is to develop a sophisticated load frequency controller suitable for use with contemporary interconnected power networks. The only form of logic that the intelligent controller employs is fuzzy logic and its variants. Our research proposes the development of a fuzzy logic load frequency controller for a power system that is interconnected between two areas. It is possible to implement it in a power system that consists of four areas using contemporary controllers. Performance of the system can be measured using dynamic characteristics such as settling time, overshoot, and undershoot. The performance characteristics of the system demonstrate that the fuzzy logic controller performs better than its competitors. On a two-area interconnected system, fuzzy gain scheduling for traditional PI and optimal load frequency controllers has been shown and simulated. These controllers are used to regulate frequency and load. The values provided by fuzzy logic demonstrate that settling time and frequency change are significantly less than those provided by PID controllers. When compared to traditional controllers, adaptive fuzzy controllers that use fuzzy gain scheduling provide superior performance under off-nominal operating conditions.

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