International Journal of Engineering Trends and Technology
ISSN: 2231–5381 / https://doi.org/10.14445/22315381/IJETT-V71I5P208

Volume 71 Issue 5, 84-97, May 2023

Original Article

Design the Potential Application of Fuzzy Logic-Based AGC and AVR for Multi-Area Interconnected Power Systems: A Case Study on Ethiopia

Abdulkerim Ali[1], Getachew Biru[2], Belachew Bantyirga[3]

[1,3]*Electrical Engineering, Bahir Dar Institute of Technology, Bahir Dar, Ethiopia.*
[2]*Electrical Engineering, Addis Ababa Science and Technology University, Addis Ababa, Ethiopia.*

[1]*Corresponding Author: abduali548@gmail.com*

Received: 09 January 2023 Revised: 17 March 2023 Accepted: 06 May 2023 Published: 25 May 2023

Abstract *- With this article, a hybrid FLC-PID controller is used to design, simulate, and control automated generation control (AGC) and automatic voltage regulator (AVR) for a four-area connected hydropower facility. This was targeted to reduce the frequency and voltage deviations that arise during load variations. Instead of the traditional PI and PID controllers, this system uses an FLC because the advanced values of the traditional regulator are fixed for load variation, but their gain values are constant. Many techniques have been proposed to resolve the drawbacks of conventional controllers. The outcomes display that if the loads continuously vary, this leads to frequency and voltage irregularities that are difficult to control without a governor. The PID control technique achieves nil steady-state error in the system's voltage and frequency; however, it shows humble dynamic performance, leading to maximal overshoot and a long settling time compared to this paper's control. The outcomes display that the FLC-PID controllers were used to improve performance and intelligently control the selection of parameters in order to achieve effective power control compared to PID control of the AGC and AVR, which is realized using MATLAB.*

Keywords *- AGC, AVR, FLC, PID, Four areas interconnected system.*

1. Introduction

A typical energy system involves a difficultly interconnected power plant with loads for residential, marketable, or manufacturing purposes. It is impossible to overstate the value of a consistent electricity supply for a nation's economy in all areas [1], [2]. Electrical power plants are typically interconnected to provide each generation unit with a sustainable, high-quality, cost-effective function. With the help of connected plants, a single generator in a power system may supply huge, intricate areas. Sustaining a reliable source of electricity for all plant customers that are of reliable, acceptable excellence is the basic aim of the power scheme process and governor. While the amount of power generated and needed is stable, the system is said to be in balance. Because irregular current power holds real and reactive constituents together, real and reactive power stabilities should be achieved together. For the control and steady operation of highly interconnected, widely dispersed power systems, matching whole production with whole load customers and corresponding system losses is required.

On the one hand, consumers now have access to very affordable and high-quality energy because of interconnection and power system reorganization. The fast-expanding power network and the use of high-speed electronic power controllers have also made power systems more unreliable. Changes in load, an abrupt rise in input power, disturbances, etc., that could lead to power system instability are the most critical issues in both small and large areas and linked power systems. This implies that the voltage and frequency of the system will change [3]. Understanding system stability is crucial to preventing dynamic collapse and potential blackouts as power networks continue to expand in size and complexity. These loads must operate at a consistent frequency and voltage with dependable, adequate, and acceptable power quality for the power system to operate and be controlled properly. System model parametric uncertainty, the nonlinearity found in a practical power system, and load disturbances provide the key control issues in frequency and voltage controllers [4]. Recent control systems need to be improved to satisfy the needs of this generation's highly vulnerable power systems to low-probability events because they are not built for fast-spreading disturbances.

An electric energy system's schedule frequency and voltage should be kept at the preferred operational level, considering schedule frequency, voltage, and load flow structure. This is maintained by retaining a tight regulator over the system's governable sources' real and reactive power. Real and reactive powers are thus independently controlled in various sections. If the schedule state is to be preserved, production adjustments should be made to balance the load deviations in the schedule circumstances [5].

Responsive energy should be accounted for in the active power transfer as efficiently as possible. This correction is required to improve voltage regulation and power system stability. Generator excitation control via AVR is the main method of controlling voltage and reactive power at a given generator level. The system frequency and voltage depart from the planned or nominal value because of the inequity between supply and demand. As the governor speed decreases as the system load increases, frequency also decreases. Therefore, the AGC is a control that resets the frequency and interchange power to their scheduled points. The fundamental target of the AGC is to preserve the target frequency, active power, and interchange power with surrounding systems by matching generation against the load and losses of the system. AGC is also a critical component of the power system process and governs delivering adequate, high-quality, and dependable electric power. It is well recognized that changes in reactive power mostly affect the voltage magnitude, but changes in real power demand primarily affect the frequency [10].

The current AGC and AVR gaps are as follows: In today's world, interconnected power systems are complicated and non-linear and must operate under uncertain conditions due to unanticipated load variations, modeling flaws, and structural changes to the system. Large overshoot and transitory frequency and voltage oscillations show how ineffective the typical control system is at handling dynamic situations. To optimize the AGC and AVR parameters while taking PID into account for either an isolated or connected power system, artificial intelligence controls can be applied to improve the dynamism of the controllers. Therefore, improved control methods are required to design control gains and achieve good frequency and voltage response performances for monitoring actual and responsive energy.

Practically everyone in the world is interested in artificial intelligence (AI) and robotics. It is the area of computer science that deals with programming computers to act like people. [6]. An AI is a characteristic of a computer or neural network that describes how they respond to data in a manner that is remarkably similar to how people do. In the past two decades, much new artificial intelligence (AI) optimization techniques have emerged that resemble biological evolution or the aging process of biological systems. These techniques include fuzzy logic control, genetic algorithms, particle swarm optimization, ant colony optimization, simulation annealing, and bacterial foraging [7]. The prior evolutionary algorithms' (GA) lack of memory is one of their key flaws since it restricts the algorithms' capacity for search and convergence. There is no stronger operator to propagate precise solutions more quickly than GA's elitist idea of memory. On the other hand, the PSO algorithm emerges as a potent stochastic optimization technique motivated by the social behaviour of organisms.

FLC has drawn a lot of attention in control systems because of its high potential for global optimization, ease of implementation, simple structure, and strong resilience capabilities, including the search for optimal PID controller parameters. The PID control technique achieves zero steady-state faults in the system's frequency; however, it has somewhat subpar dynamic performance, resulting in maximum overshoot and a long settling time. Using FLC, it is possible to modify the basic gain of the AGC and AVR settings automatically and return the system to its nominal frequency and voltage for a variety of wide-ranging load changes. Due to their high degree of dependence, integrating renewable energy sources into the electrical grid brings forth new problems. For everyday management, power systems require sophisticated control techniques [8]. The emerging trend in the control domain is to combine artificial intelligence algorithms like FLC, GA, and PSO algorithms with traditional controllers to tackle problems with frequency, active power flow, and voltage control in power systems. The key objective of developing FL-based voltage and frequency control is to confirm a steady and consistent power system process. The Fuzzy-PID controller, which can be applied to all nonlinearities, has the best effectiveness of all controllers used in AGC and AVR [9].

So, this paper introduces and compares two methods for the voltage and frequency control of a multi-area interconnected power system which are simulated in MATLAB/Simulink and compared with a conventional control structure. The first method proposes an FLC-PID for voltage control, and the second method proposes an FLC-PID for frequency control and the stabilization of generator frequency oscillations utilized in AGC and AVR. The simulations are carried out in load variation.

2. Literature Review

Tilahun et al. [14] presented the use of ANFIS for automatic generation control in one and two areas that provide modeling, development, and an investigational study for the hydroelectric system. This was done to reduce frequency variations that happen during power production. The outcomes demonstrate that the ANFIS controller outperforms both the PID and the FLC in terms of performance. However, because the frequency is controlled, the plant's voltage is not kept in a healthy state.

Rishabh et al. [15] examined the effectiveness of two nearby hydroelectric systems for AGC using several controllers, including ANN, FLC, and PID, aimed at the best regulator. In this case, it is a hydroelectric plant with a single area; the appearance of AGC via FLC produced better results than AGC via PID governor. Additionally, ANN was trained using information made from the outcomes of simulations of the optimal controller, and the trained artificial neural network model was utilized to monitor the hydropower plant's appearance at its peak. Huge settling time and steady-state inaccuracies characterize the trained ANN model.

Sirisha et al. [17] looked at the AGC of interrelated energy systems and demonstrated how several regulators, including PI, PID, and fuzzy PI regulators, affected their appearance. When compared to the PI regulator, the appearance of the AGC with an FLC-PI regulator was greater. However, the authors did not assess the combined effects of the fuzzy logic and ANN models.

Adane [18] introduced the use of fuzzy logic to create AGC problems in power system studies. A dual area has been considered in this article. Using the available response as a comparison point, the frequency variation for a step load rise at one location is displayed based on time.

Baldevraj et al. [20] described the automatic generation control (AGC) issue in studies of power systems can be solved by designing a fuzzy controller using fuzzy logic. In this work, a two-area power grid has been taken into account. Using the classical integral controller, the frequency deviation for a step load increase in one area is displayed as a function of period and contrasted with the available response. This work's flaw was not contrasting its findings with those of traditional PID controllers. The sole comparison the authors made was with a traditional integrated controller. Additionally, they only employed one step load increase for two area systems.

Kavita et al. [21] presented optimal correction of the PID regulator for LFC and AVR of dual-area connected power plants and demonstrated the efficacy of the intended system by contrasting the system with a traditional PI regulator and a traditional integral regulator. However, the PID and fuzzy logic were not compared, nor were their combined effects.

The literature has suggested a variety of techniques to boost the efficiency of hydropower plant operations, including [4], [8]-[10], [22], [31], [35], [37], and [40] AGC and AVR utilizing FLC produced superior results than AGC and AVR using other controllers, according to the majority of literature reviews. To decrease the frequency and voltage variations that happen through power generation and to enhance the effectiveness of the regulator, this work describes the design, modelling, and control of an AGC and an AVR for a hydroelectric power system utilizing hybrid FLC-PID control. This research considers a connected power plant with four areas, in contrast to earlier studies that only looked at tests on a single-area hydropower plant. The main goals of this study are to offer the appropriate processes for tie-line power exchange and to enhance system appearance in transient conditions anytime there's a load disruption.

3. Material and Methods

3.1. Automatic Voltage Regulator

It is a generator initiation scheme that regulates both the system's reactive electricity and terminal voltage [26]. The AVR is made up of the following four main components and additions.

3.1.1. Amplifier

Transmitting fault signal to the exciter and is signified:

$$\frac{V_R(s)}{Ve(s)} = \frac{k_a}{1+sT_a} \tag{1}$$

k_a and T_a are amplifier gain and time constant, respectively.

3.1.2. Exciter

Provides an exciting field in the exciter to enhance a large generator and is signified by:

$$\frac{V_F(s)}{V_R(s)} = \frac{Ke}{1+sT_e} \tag{2}$$

k_e and T_e is gain and time constant of the exciter.

3.1.3. Generator

Generator is producing the voltage generator and signified by:

$$\frac{Vt(s)}{V_F(s)} = \frac{k_g}{1+sT_g} \tag{3}$$

k_g and T_g = generator gain and time constant, respectively.

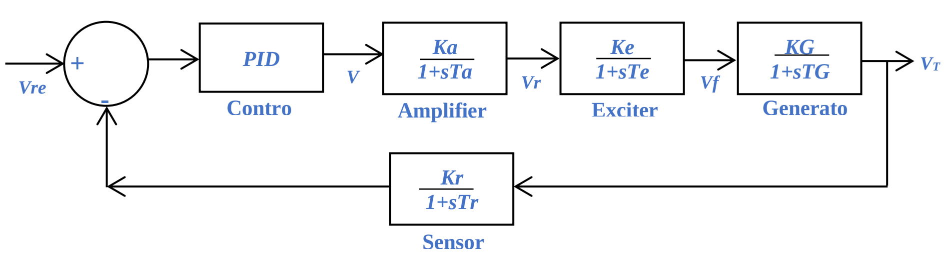

Fig. 1 Schematic diagram of AVR

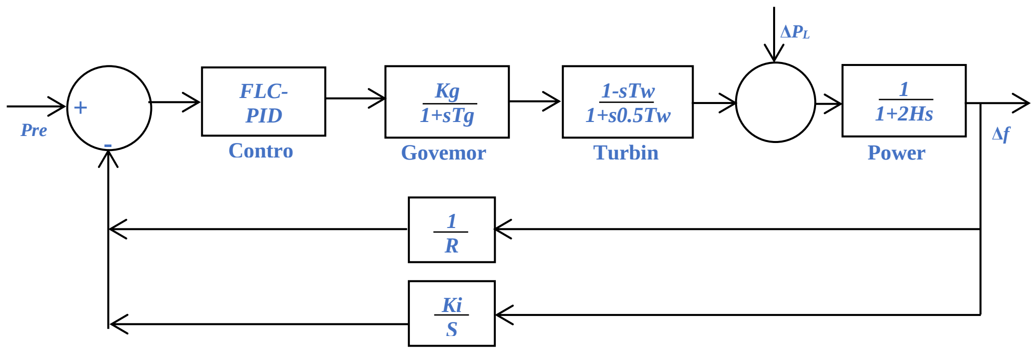

Fig. 2 Schematic diagram of AGC

3.1.4. Sensor

In order to generate an error signal with a bridge fixer, the sensor makes a comparison between the output voltage and a set point signal.

$$\frac{Vs(s)}{Vt(s)} = \frac{k_r}{1+sT_r} \tag{4}$$

k_r and T_r are sensor gain and time constant. A diagram of AVR through PID is displayed in the above figures.

3.2. Automatic Generation Control

The elimination of frequency and exchange power faults in the system is the real aim of AGC [28]. The components are as follows:

3.2.1. Governor

Controls the system's actual power flow and tracks the movement of the governor-maintained valves.

$$\frac{P_e(s)}{Pv(s)} = \frac{k_g}{1+sT_g} \tag{5}$$

k_g and T_g are governor gain and time constant correspondingly.

3.2.2. Turbine

It converts electrical energy to mechanical energy.

$$\frac{\Delta P_m(s)}{\Delta Pe(s)} = \frac{1-sT_w}{1+s0.5T_w} \tag{6}$$

T_w is water starting time.

3.2.3. Power System

The generator and the electrical load constitute the energy scheme and will be:

$$\frac{2Hd^2\Delta\delta}{\omega_s dt^2} = \Delta P_m - \Delta P_e$$

$$\frac{\Delta f(s)}{\Delta Pa(s)} = \frac{1}{2Hs+D} \tag{7}$$

Where, D and H damping constant and mass inertia load individually.

3.2.4. Speed Regulator

It is a sensor for detecting the output error and sending information to the controller.

$$\frac{\Delta PG(s)}{\Delta f(s)} = \frac{1}{R} \tag{8}$$

Where, R is the regulator constant. The diagram of AGC is:

3.3. PID Controller

Conventional PID control systems frequently employ AGC and AVR [17]. The variance between the anticipated set point and the actual plant output, a measurable process variable, is used to calculate the error value. It also attempts to reduce variances by modifying the regulated variables. Due to their various advantages, which include a wide range of relevance, a quality close to optimal, and ease of use for plant operators, they are frequently used in industrial processes. The transfer function and block diagram of PID can be:

$$G_{PID}(s) = K_p + \frac{K_i}{s} + K_d s \tag{9}$$

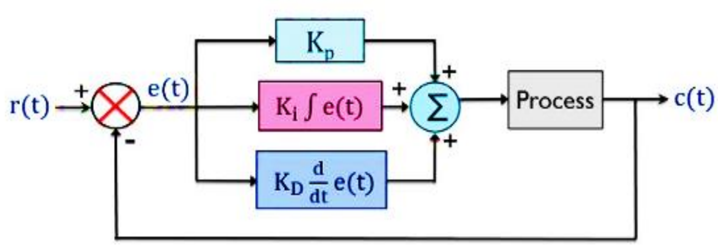

Fig. 3 Schematic diagram of PID

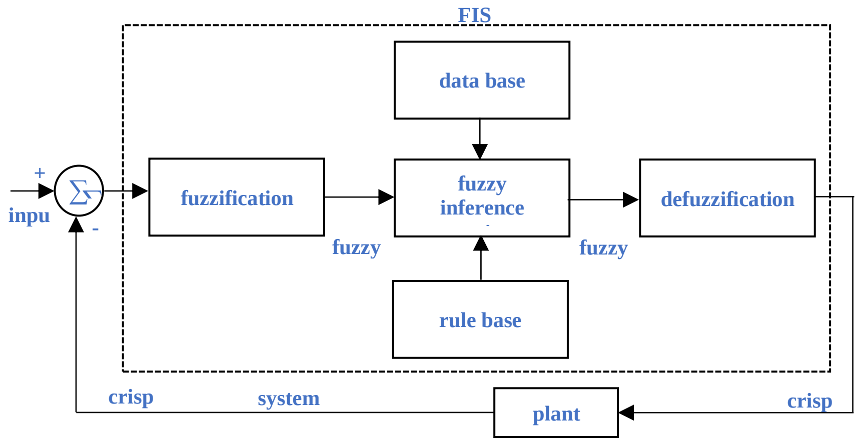

Fig. 4 Schematic diagram of FLC

3.4. Fuzzy Logic Controller

In 1965, Zadeh proposed the use of fuzzy logic. In human reasoning, fuzzy logic is a technique accustomed to model vagueness. FL is excellently aimed at describing vague data and terminology, for example, explanations in human linguistics, in an intuitive manner. Due to its knowledge-based algorithm, improved nonlinearity treatment capabilities, and freedom from system modeling, fuzzy control has become more common over the past three decades. Linguistic control is responsible for the popularity of the FLC. Here, it's unnecessary to have a precisely measured model of the plant to be [40]. As a result, the FLC has proven to be quite useful in the field due to its ability to provide complicated non-linear control to even uncertain non-linear systems. Because no constraint guesstimate is necessary when developing regulators for nonlinear systems, their primary benefit is that regulator settings will be attuned quickly to the system's dynamics. In addition to the aforementioned attributes, an FLC also creates decent performance in terms of constancy, accuracy, dependability, and quickness. The system inputs for control systems are feedback error and variation of error, and the control operation is the system output using simple IF-THEN rules. Table-I assumes the appropriate fuzzy rule base, where NB, NM, NS, Z, PS, PM, and PB stand for negative large, negative medium, negative small, zero, positive small, positive medium, and positive big. The newly created fuzzy controller will operate similarly to a PID controller with time-varying parameters. The center of gravity defuzzification method and the Mamdani-type fuzzy inference system have both been employed [22]. The architecture of FLC is given by:

Fuzzification changes crisp values into fuzzy membership functions that FLC can recognize. The FIS, which is utilized to infer rules from rules based on inputs to product outputs, is the system's brain. Sugeno and Mamdani, two alternative FIS, are available. The Mamdani FIS is taken into account for demonstration in this work. In a process identified as defuzzification, the fuzzy output variables are once again transformed into clear values so that the result is likewise comprehensible to the average person [9]. The frequency variation and its derivation will serve as the input membership functions, which are as follows:

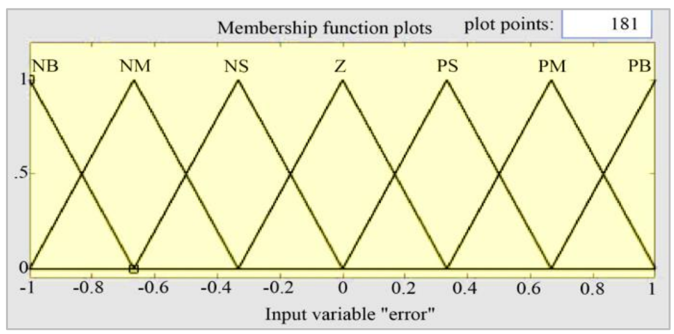

Fig. 5 Membership function of error

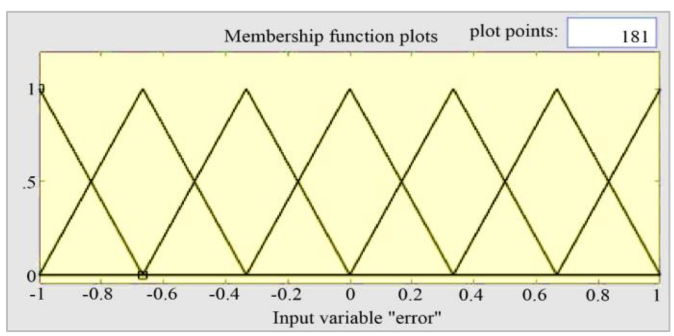

Fig. 6 Membership function of the derivative of the error

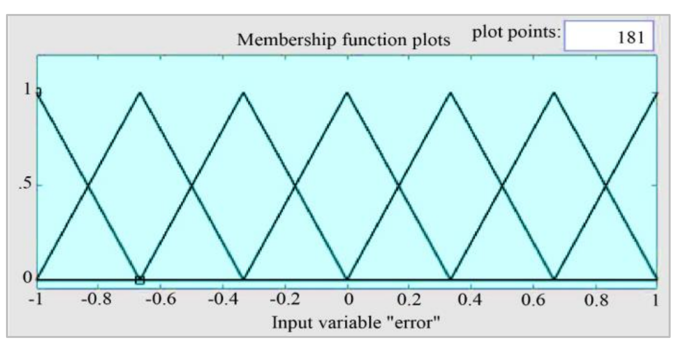

Fig. 7 Membership function of output table I. FLC rule base

Table 1. FLC rule base

e \ de	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NM	NB	Z	NS
NM	NB	NB	NM	NS	NS	PS	PS
NS	NB	NM	NS	Z	Z	PM	PM
Z	NM	NS	Z	PS	PS	PM	PB
PS	NS	Z	PS	PM	PM	PB	PB
PM	Z	PS	PM	PB	PB	PB	PB
PB	PS	PM	PB	NB	NM	NS	PB

3.5. AGC and AVR Relation

Since the excitation regulator of the generator has a smaller time persistent supplied by the field winding than the AGC, It works as slowly. It has a larger time constant donated by the turbine and generator instant of inertia. The AGC and AVR are reflected individually. As a result, a transient in the excitation regulator disappears considerably more quickly and has no impact on AGC. In reality, the two don't intersect; the connection is there, but in the other direction because AVR impacts how much electromagnetic field is produced [34]. This electromotive force restricts the amount of real power, which is felt in AGC as a result of AVR. The following equation results from a slight voltage influence on the real power:

$$\Delta P_e = P_s \Delta\delta + K_2 E' \tag{10}$$

Where, K_2, $\Delta\delta$, P_s are constant, load angle and synchronizing power coefficient, respectively. And the active output power will be:

$$\Delta P_{eo} = \Delta f \frac{1}{R} = V_d * I_d \tag{11}$$

By inserting a small rotor angle effect on the voltage of the generator terminal, we may write

$$\Delta V_t = K_5 \Delta\delta + K_6 E' \tag{12}$$

Where K_5 and K_6 are changed in voltage for a minor variation in the stator and load angle, respectively.
And the reactive power will be:

$$\Delta Q_{eo} = V_q * I_q \tag{13}$$

We can determine the stator voltage as follows: by adjusting the transfer function of the generator's field to account for the influence of the load angle:

$$E' = \frac{K_g}{1+T_g}(V_f - K_4 \Delta\delta) \tag{14}$$

The comprehensive schematic figure of AGC and AVR for one location:

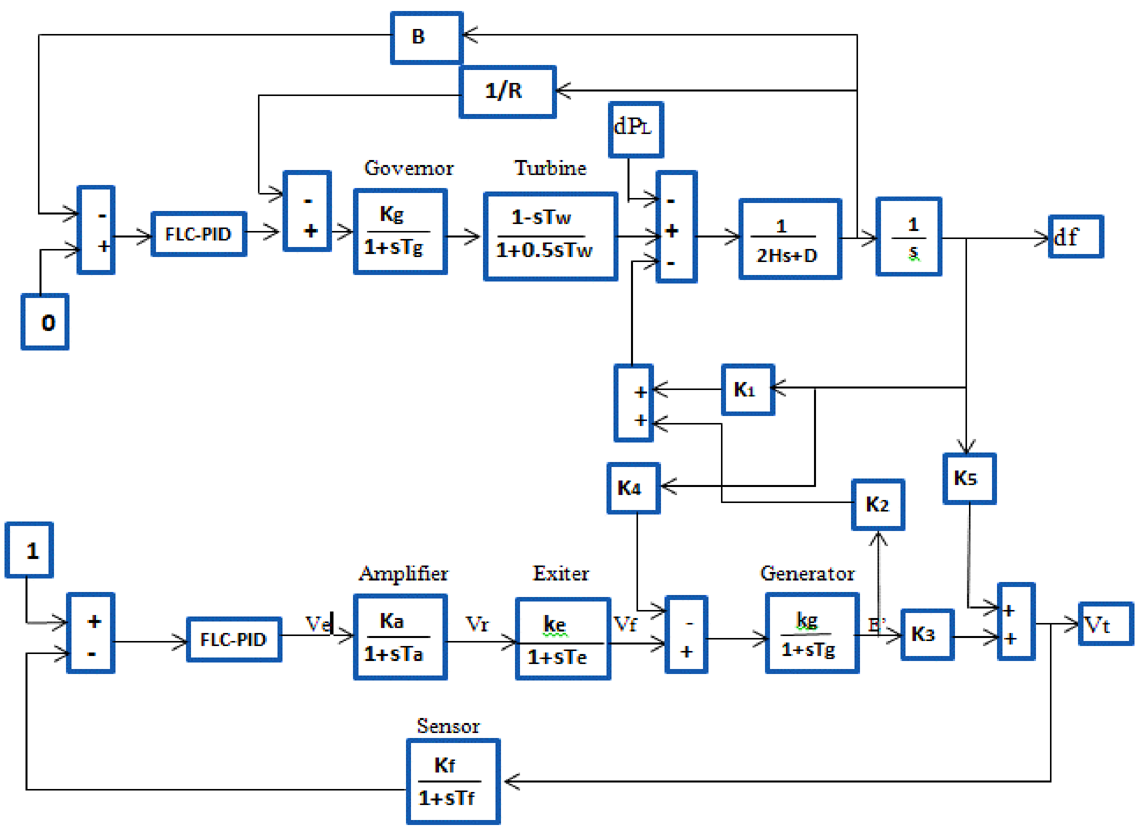

Fig. 8 Schematic diagram of AGC and AVR loop

3.6. Four-Area Interconnected Structure

The majority of power systems are made up of several components, some of which may exhibit nonlinear behavior. Due to the tie-line that connects these sites, control over power flow and frequency is required. Within a connected system, tie lines link related regions. A power exchange takes place through the tie line connecting the four places when the frequencies in those areas are in opposition to one another.

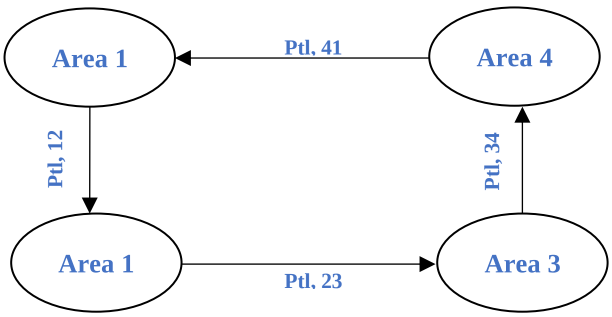

Fig. 9 Four areas linked scheme

Area i to area j tie-line power flow can be illustrated as:

$$P_{tie,ij} = \frac{E_i E_j}{X} sin(\delta_i - \delta_j) \tag{15}$$

Where E_i and E_j are the voltage magnitude of each power, X is transmission impedance and δ_i, δ_j each load angle. The tie line power can be represented:

$$\Delta P_{tie,ij} = T_{ij} \Delta\delta_{ij} = T_{ij}(\delta_i - \delta_j) \tag{16}$$

Where synchronizing coefficient

$$T_{ij} = \frac{|E_i||E_j|}{P_{ri}X} \cos((\delta_i - \delta_j)) \tag{17}$$

The detailed schematic diagram modeling of four areas hydro-hydropower system for load frequency control as displayed:

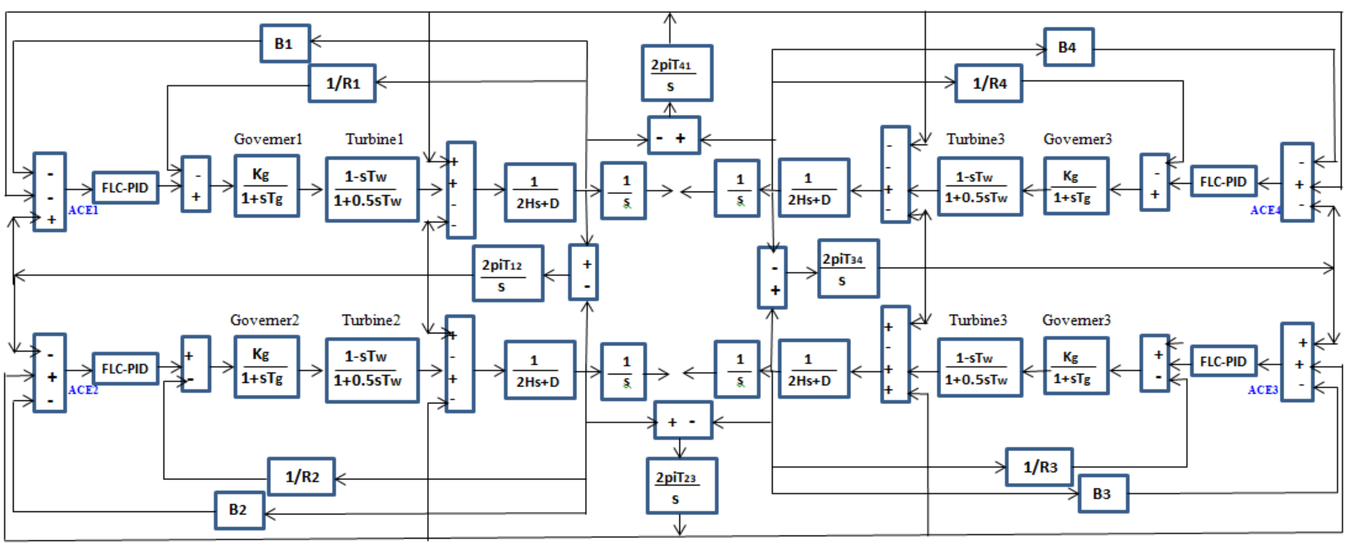

Fig. 10 Block diagram of four areas interconnected system

4. Simulation Result and Discussion

To demonstrate how well AGC and AVR perform using MATLAB software, single and interconnected power systems with PID and FLC-PID controllers are constructed in this work. The parameters of the generators connected to the endless bus with the transmission line of the four hydroelectric systems in Ethiopia (Tekeze, Gilgelgibe II, Tana Beles, and Tiss Abay) are specified in Table 2&3.

Table 2. Parameters constant for AGC

Parameter	Area 1	Area 2	Area 3	Area 4
Generator constant	T_{g1}= 0.5s k_{g1}=1	T_{g2}= 0.5s k_{g2}=1	T_{g3}= 0.5s k_{g3}=1	T_{g4}= 0.5s k_{g4}=1
Turbine constant	T_{w1}= 0.1s	T_{w2}= 0.1s	T_{w3}= 0.1s	T_{w4}= 0.1s
Inertia constant	H_1=3	H_2=3	H_3=3	H_4=3
Speed constant	R_1=0.05	R_2=0.04	R_3=0.05	R_4=0.04
Load disturbance	ΔP_{L1}= 0.05pu	ΔP_{L2}= 0.06pu	ΔP_{L3}= 0.05pu	ΔP_{L4}= 0.06pu
Tie-Line Coefficient constant	ΔT_{12}=0.012pu	ΔT_{23}=0.012pu	ΔT_{34}=0.012pu	ΔT_{41}=0.012pu
Normal Frequency	f_1=50 Hz	f_2=50 Hz	f_3=50 Hz	f_4=50 Hz

Table 3. Parameters constant for AVR

Constraint	Area 1	Area 2	Area 3	Area 4
Amplifier constant	T_{a1}=0.04s k_{a1}=40	T_{a2}=0.04s k_{a2}=40	T_{a3}=0.04s k_{a3}=40	T_{a4}=0.04s k_{a4}=40
Exciter constant	T_{e1}= 0.4s k_{e1}=1	T_{e2}= 0.3s k_{e2}=1	T_{e3}= 0.4s k_{e3}=1	T_{e4}= 0.3s k_{e4}=1
Generator constant	T_{g1}= 1s k_{g1}=1	T_{g2}= 1s k_{g2}=1	T_{g3}= 1s k_{g3}=1	T_{g4}= 1s k_{g4}=1
Sensor constant	T_{f1}= 0.05s k_{f1}=1	T_{f1}= 0.03s k_{f2}=1	T_{f1}= 0.05s k_{f3}=1	T_{f1}= 0.03s k_{f4}=1
PID constant	k_{p1}=0.4 k_{d1}=0.3 k_{i1}=0.2	k_{p2}=0.4 k_{d2}=0.3 k_{i2}=0.2	k_{p3}=0.4 k_{d3}=0.3 k_{i3}=0.2	k_{p4}=0.4 k_{d4}=0.3 k_{i4}=0.2

Source: Dynamic generator parameter in Ethiopia

4.1. Simulation Result of the Single Area

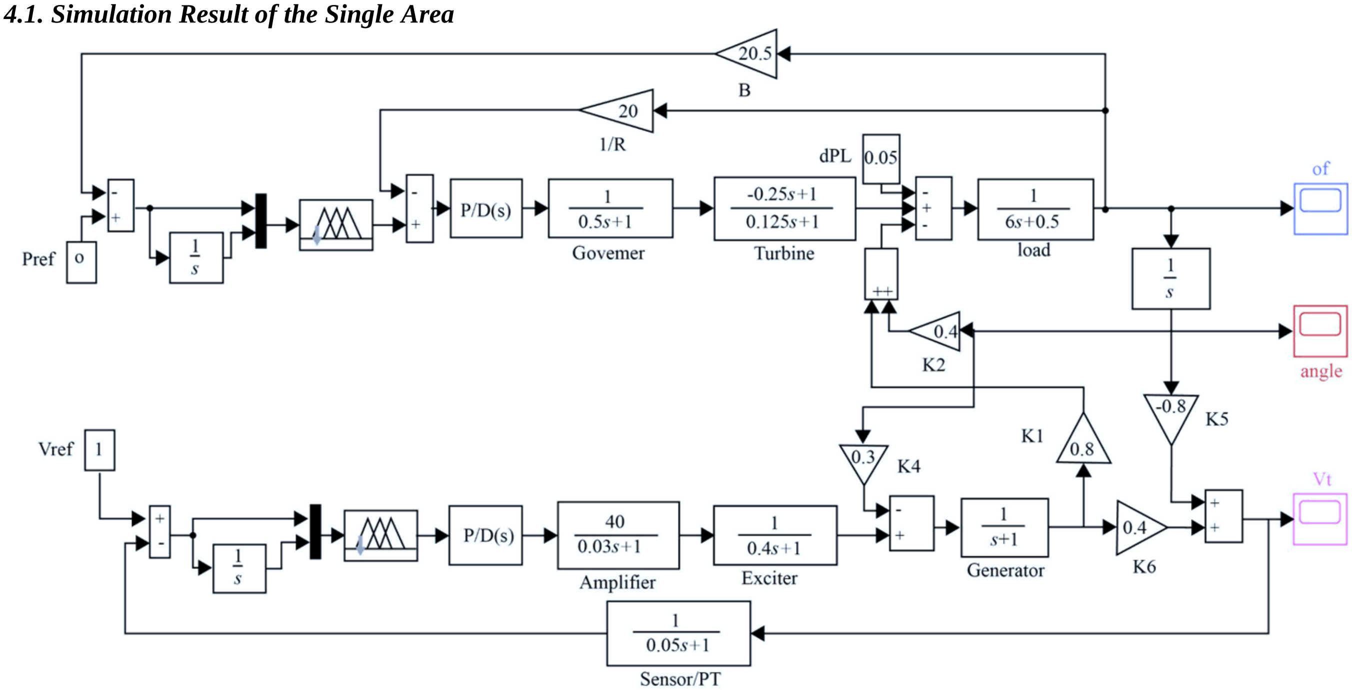

Fig. 11 Simulation diagram of a one region

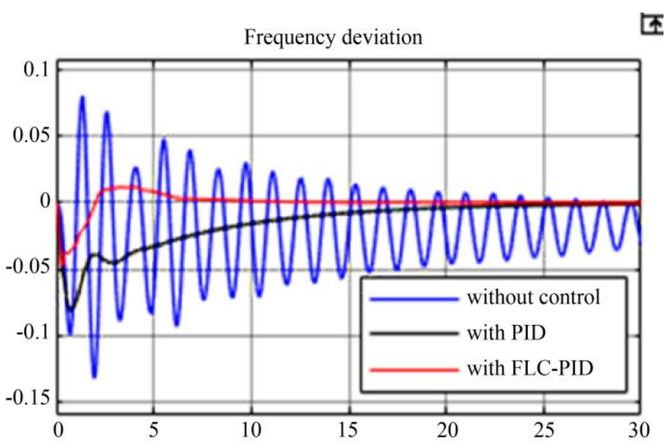

Fig. 12 Frequency change response of single area

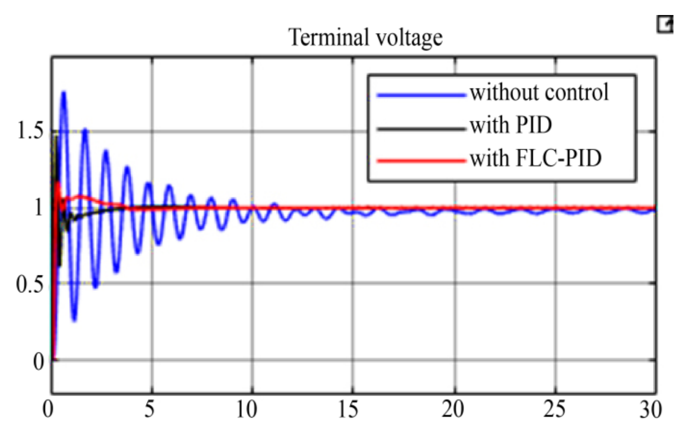

Fig. 13 Voltage response of single area

4.2. Simulation Result of Four Area Interconnected Systems

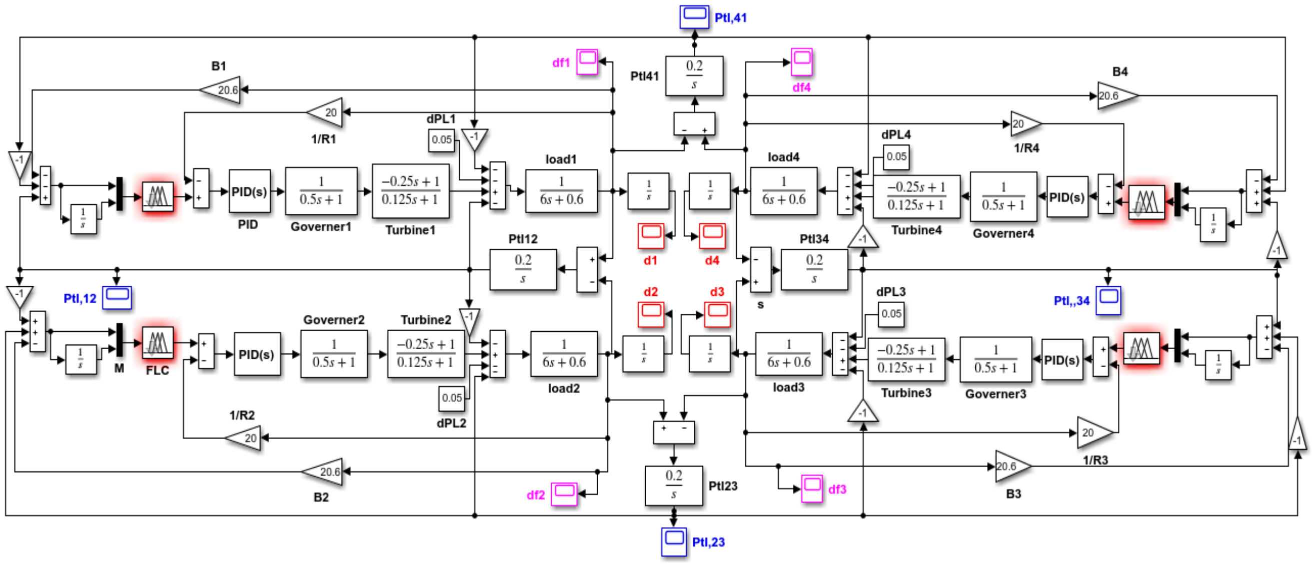

Fig. 14 Block diagram of the four-area interconnected system

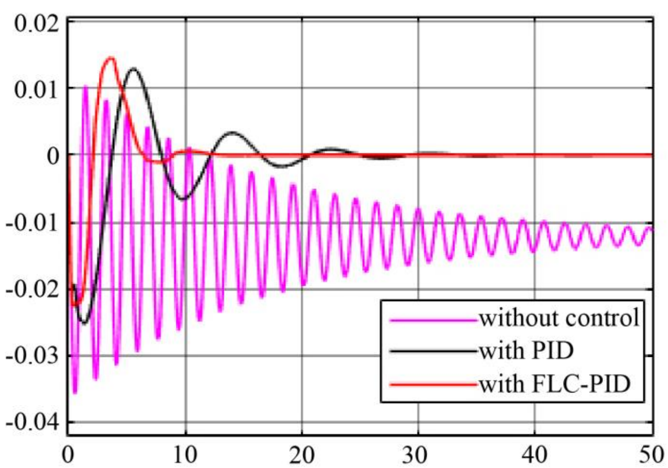

Fig. 15 Frequency deviation of area 1

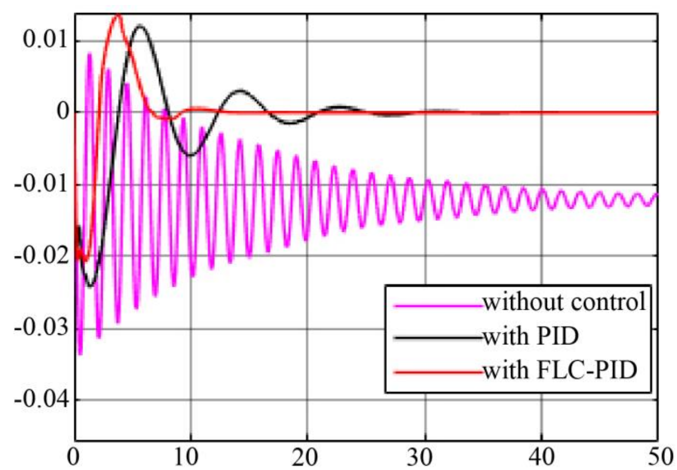

Fig. 17 Frequency deviation of area 3

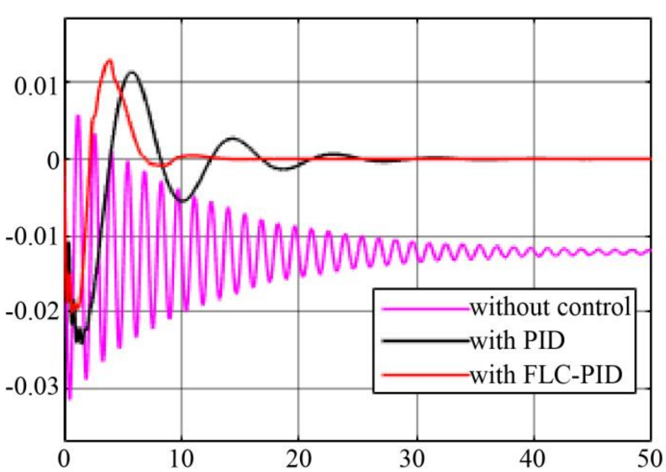

Fig. 16 Frequency deviation of area 2

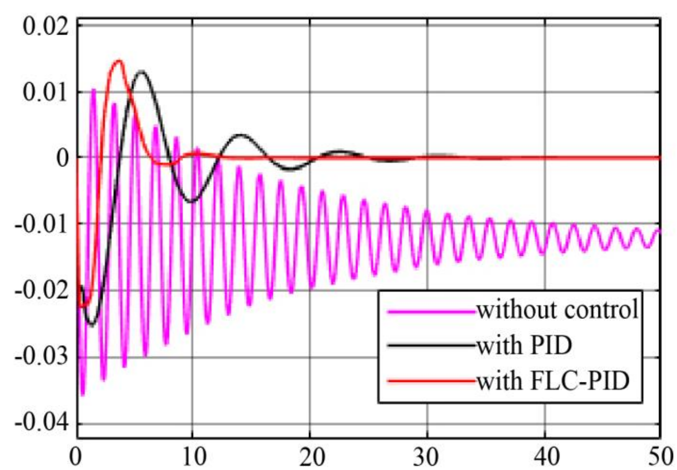

Fig. 18 Frequency deviation of area 4

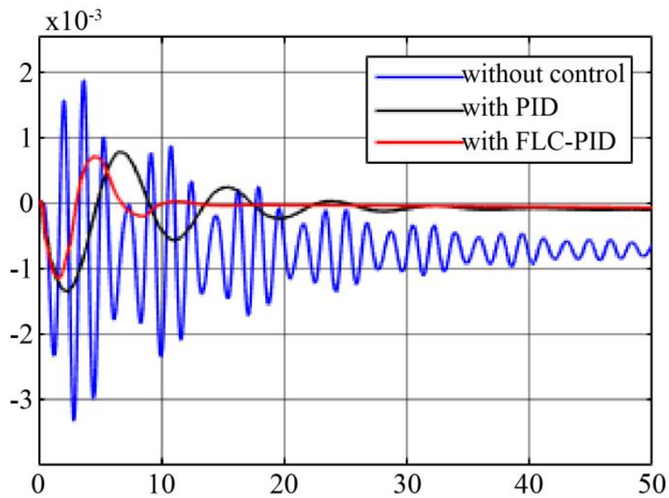

Fig. 19 Tie line power change, 12

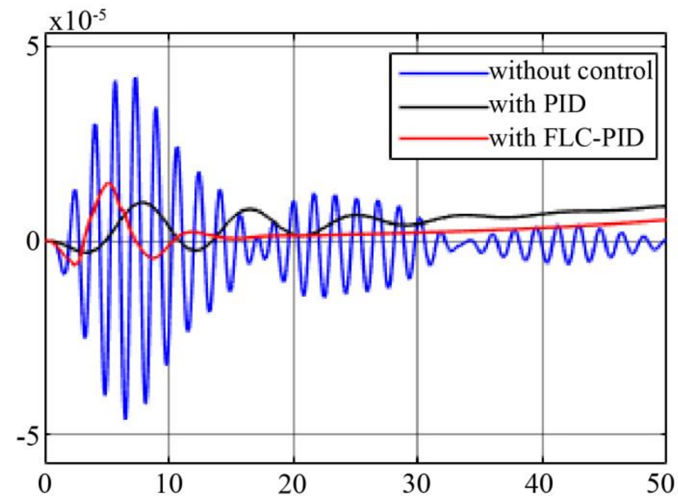

Fig. 22 Tie line power change, 41

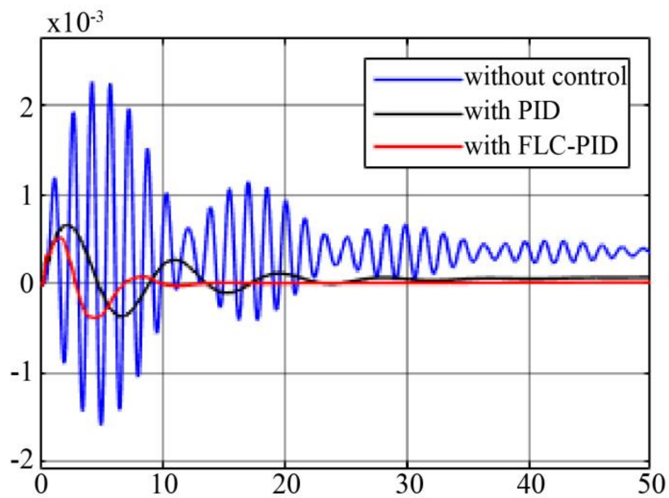

Fig. 20 Tie line power change, 23

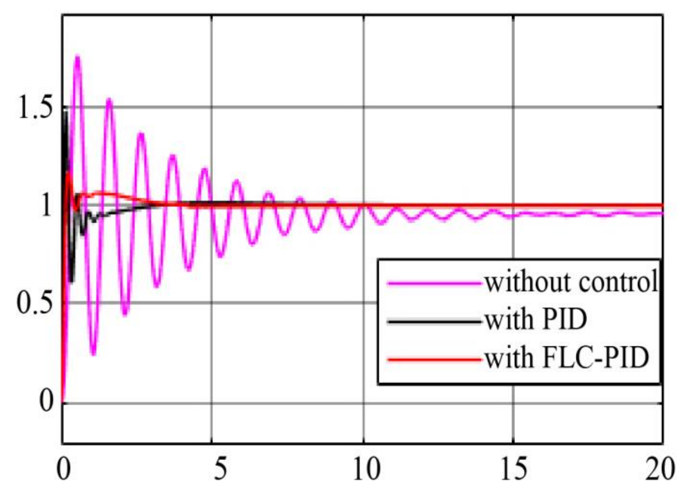

Fig. 23 Terminal voltage 1

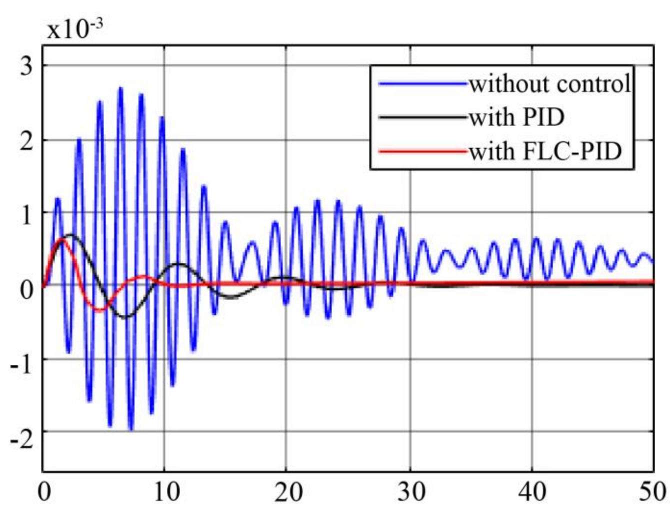

Fig. 21 Tie line power change, 34

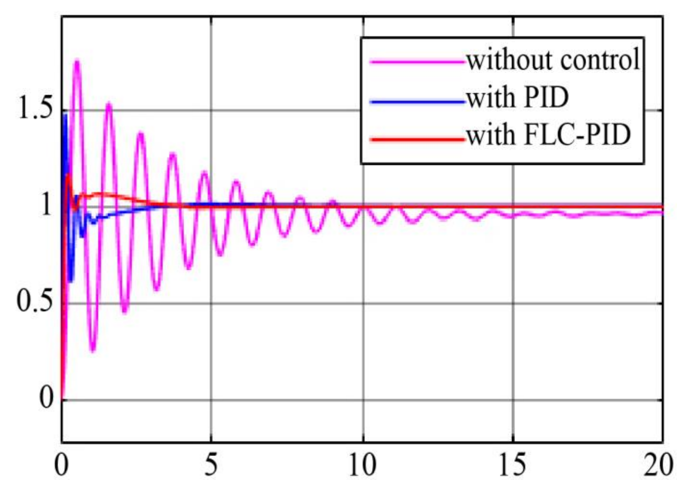

Fig. 24 Terminal voltage 2

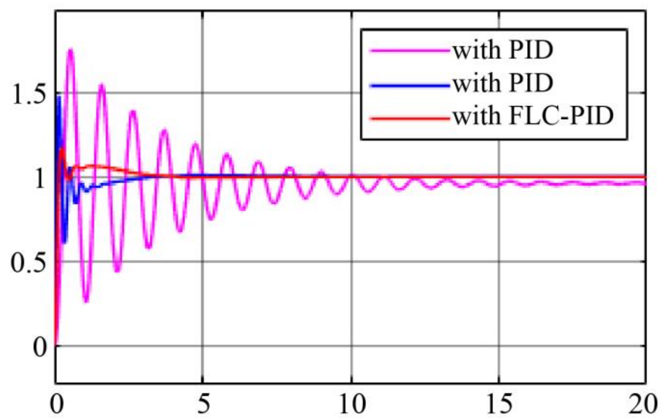

Fig. 25 Terminal voltage 3

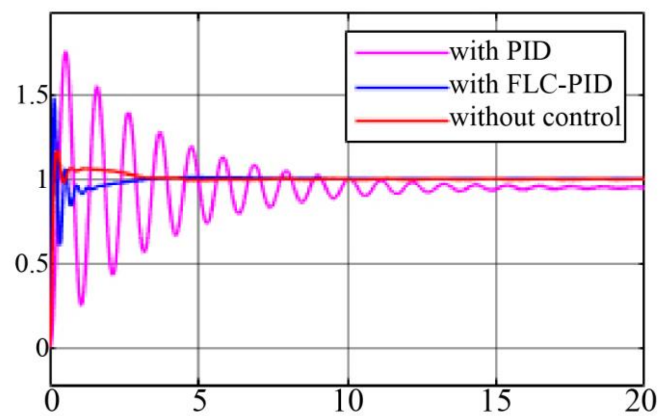

Fig. 26 Terminal voltage 4

4.3. Result Discussion

This study illustrates both single and multiple interconnected hydropower plants. The performance of the hydropower plant's AGC and AVR were assessed using PID and FLC controllers. The simulations for the self-supporting and networked hydraulic plants were carried out using MATLAB software. Figs. 12 and 13 show, respectively, the single-area power plant with the output frequencies and voltages of the AGC and the AVR. The results indicate that a lower AGC and AVR performance coupled with an increased frequency and voltage deviation leads to very significant steady-state inaccuracies. When the frequency deviation is between 1% (0.5 Hz) and the nominal value, it is within the power plant's permitted tolerance (50 Hz).

Without controllers, AGC and AVR had to settle periods of 70 s, overshoots of 10%, and frequency errors of -0.012 pu for the frequency response; and settling periods of 16 s, overshoots of 79%, and voltage errors of -0.1 pu for the voltage response. This indicates that for the single-area hydroelectric system, the actual frequency deviates from the nominal value (50 Hz) by 5 Hz (0.1 pu), and the voltage deviates from the nominal value by 9.45 kv (0.79 pu). Allowing this operating condition to continue will have an effect on performance and harm various system parts. To resolve this problem and generate a steady power supply, additional controllers, such as PID and FLC-PID, were also used to address this issue and produce a steady power supply. When AGC and AVR with PID were used for the frequency response, they resulted in settling times of 20 s, overshoots of 7%, and frequency errors of 0. The system of AGC and AVR in a single region with FLC-PID for the frequency response performed with a settling period of 5 seconds, an overshoot of 4%, and a steady state error of 0. The AVR and AGC with PID's voltage response resulted in a settling time of 5 seconds, a 50% overshoot, and a steady state error of 0. The voltage response of the single area hydropower plant's AVR and AGC with FLC-PID had settled in 3 s with an overshoot of 18% and a steady state error of 0. The results show that AGC and AVR with applied FLC-PID are more steady and rapid than when AGC and AVR are employed without and with a PID controller for a single area power system.

A multi-area interconnected hydroelectric system has trouble managing the scheduled frequency range in contrast to a single area. In addition to operating within the appropriate frequency range, variations in the tie-line energy flow from the four-region hydropower plant should be observed based on prescribed values. Interconnected power plants can maintain a certain level of power quality, but the control mechanism is still challenging to execute because of their time-varying and nonlinear behaviours. A rapid switch in control action is needed to address the interrupted system at these four neighbouring hydropower sites. Areas 1, Area 2, Area 3, and Area 4 were found to have high levels of dynamic oscillations, frequency variations, and steady-state faults using AGC and AVR only, as illustrated in Figs. 15–18; tie-line power variation can also be seen in Figs. 19–22. The results reveal that the frequency deviates from the normal (50 Hz) by 1.8 Hz (0.036 pu), and the voltage deviates by 10.125 kV (0.75 pu) from the nominal (13.5 kV).

This is not a sufficient frequency and voltage fault because the frequency and voltage change in a networked hydroelectric facility is estimated to be very small even when the plant has additional renewable energy sources like wind power plants, which also contribute to the significant fluctuation that arises in the system. Artificial intelligence control, for example, is crucial in this situation as a swift and effective performance regulator. The frequency responses of the settling period, overshoot, and frequency error were all 60 seconds, 3.6%, and 0.012 pu when AVR and AGC controllers were only used. But when AGC and AVR were used with PID, the frequency responses of the settling period, overshoot, and frequency error were all 25 seconds, 2.4%, and 0.

The settling period, overshoot, and frequency variation for AGC and AVR with an FLC-PID controller are also 6 s, 2.1%, and 0, respectively. Figs. 16–18 show the frequency responses of the AGC in Areas 2, 3, and 4, using PID and

FLC-PID, and they all have the same result. The settling time, overshoot, and voltage deviation were 16 s, 75%, and 0.1 pu without the controllers of AGC and AVR. This is shown in Figs. 23–26. However, using AVR and AGC with PID control led to a voltage response with a settling time, overshoot, and voltage change of 5 s, 50%, and 0. The settling time, overshoot, and voltage deviation were reduced to 3 s, 18%, and 0 with the help of AVR and AGC with FLC. The hydropower plant's dynamic oscillation, voltage deviation, and settling time were all improved when AVR and AGC with FLC-PID were utilized instead of AVR and AGC without and with a PID controller. Using PID and FLC-PID, Areas 2, 3, and 4 of the AVR function similarly to Area 1 in terms of voltage responses, as shown in Figs. 24 - 26.

5. Conclusion and Future Work

The key target of this article was to design, model, and regulator the operation of the AGC and AVR on four interconnected power systems through the use of the FLC-PID controller. The system responds dynamically to a load modification of 0.1 pu. An FLC controller's peak overshoot, settling time, and steady-state error are significantly lower than those of a traditional PID controller. The settling time, overshoot, and steady-state error are decreased by 58.33%, 33.33%, and 1.2%, respectively, in contrast to the frequency response of the AGC without a controller. In contrast to the frequency response of AGC with PID, the FLC controller reduces the settling time, overshoot, and steady-state error by 76%, 12.5%, and 0%, respectively. Moreover, the settling time, overshoot, and steady-state error are all decreased by 68.75%, 33.3%, and 90%, respectively, when AVR is applied with a PID and compared to AVR without the controller.

In contrast, compared to AVR with PID, the voltage response of AVR with FLC has experienced a decrease in settling time of 40%, overshoot of 64%, and steady-state error of 0%, respectively. As a result, when AGC and AVR with FLC were used instead of with and without a PID controller, the hydropower plant's dynamic oscillation, frequency and voltage deviation, and settling time of the voltage and frequency response were all improved. The results of all comparable simulations, which have been run for various load increases, are consistent with the research's conclusions. The system regulators will be adjusted utilizing various modern optimization approaches for subsequent work.

Acknowledgements

The journalists sincerely thank Getachew B. and Belachew B., whose insightful comments and suggestions greatly enhanced the manuscript's substance. The writers are also appreciative of the availability of research resources for the completion of the article.

Author contributions

Abdulkerim Ali: Conceptualization, Methodology, Software, Field study, Data collection, Writing-Original draft preparation, Software, Field study. Getachew Biru: Supervision, Writing-Reviewing and Editing Belachew Banteyirga: Co-advisor: Validation, Visualization, Investigation.

References

[1] Nishchitha V A, Monisha Pattnaik, and Mrs.Susmita Deb, "LFC of a Four-Area Interconnected Thermal-Hydro-Nuclear-Wind Power System with Non-Linearity using FLC-PID Controller," *International Journal of Engineering Research & Technology*, vol. 10, pp. 543-547, 2021. [Google Scholar] [Publisher Link]

[2] Wai-Kai Chen, *Linear Networks and Systems*, Belmont, CA, USA: Wadsworth, pp. 123–135, 1993. [Publisher Link]

[3] E.A. Duque, J.D. González, and J.C. Restrepo, "Developing Sustainable Infrastructure for Small Hydro Power Plants through Clean Development Mechanisms in Colombia," *International Conference on Sustainable Design, Engineering, and, Construction*, vol. 145, pp. 224–233, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[4] Kajal Karna, and G.Veeranna, "Improved PSO Algorithm Assisted AGC in Interconnected Power System," *International Journal of Recent Technology and Engineering*, vol. 8, pp. 118-123, 2019. [Publisher Link]

[5] Baraka Kichonge, "The Status and Future Prospects of Hydropower for Sustainable Water and Energy Development in Tanzania," *Journal of Renewable Energy*, pp. 1–12, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[6] Reddy C., Krishnarayalu M., "AGC of Multi-Area Power System using Active Disturbance Rejection Control," *International Journal of Engineering Trends and Technology*, pp. 212-221, 2017. [Publisher Link]

[7] K. Jagatheesan, and B. Anand, "Automatic Generation Control of Three Area Hydro-Thermal Power Systems with Electric and Mechanical Governor," *IEEE International Conference on Computational Intelligence and Computing Research*, pp. 1–6, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[8] Adel Akbarimajd et al., "Nonlinear Multi-Agent Optimal LFC Based on Feedback Linearization of Wind Turbines," *IEEE Transactions on Sustainable Energy*, vol. 10, pp. 66-74, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[9] Reena Kumari, and Mr. Ram Avtar, "Frequency Stabilization of Two-Area Interconnected Power System using FLC and PID Controller," *International Journal of Engineering Research & Technology*, vol. 2, no. 5, pp. 1368-1372, 2013. [CrossRef] [Publisher Link]

[10] Sophia Jasmine G, Magdalin Mary D, and Thenmalar K, "Fuzzy Logic Based LFC of Power System," *Materials Today: Proceedings*, vol. 45, pp. 8170-8175, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[11] Helbert Espitia, Iván Machón, and Hilario López, "Optimization of a Fuzzy AVR Using Real-Time Recurrent Learning," *Processes*, vol. 9, no. 6, p. 947, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[12] Yogendra Arya et al., "AGC Performance Amelioration in Multi-Area Interconnected Thermal and Thermal-Hydro-Gas Power Systems using a Novel Controller," *Engineering Science and Technology, an International Journal*, vol. 24, no. 2, pp. 384-396, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[13] Sawat Yukhalang, "LFC of Photovoltaic-Gasifier for Interconnected Two-Area Power Systems," *International Journal of Engineering and Advanced Technology*, vol. 9, pp. 2101-2105, 2019. [CrossRef] [Publisher Link]

[14] Tilahun Weldcherkos, Ayodeji Olalekan Salau, and Aderajew Ashagrie, "Modeling and Design of an AGC for Hydropower Plants using NFC," *Energy Reports, Elsevier*, vol. 7, pp. 6626–6637, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[15] S.Divya, and M.Balaji, "Development and Performance Analysis of Fuzzy Logic Tuned PID Controller for Level Process using PLC," *SSRG International Journal of Electrical and Electronics Engineering*, vol. 5, no. 2, pp. 5-11, 2018. [CrossRef] [Publisher Link]

[16] Archana Tahiliani, and Prof. Amit Panchal, "Dynamic Response Analysis through Conventional Methods and Fuzzy Logic for Automatic Load Frequency Control," *SSRG International Journal of Electrical and Electronics Engineering*, vol. 1, no. 2, pp. 1-6, 2014. [CrossRef] [Publisher Link]

[17] Sirisha Annam, Dr.K.Radha Rani, and J.Srinu Naick, "Automatic Generation Control of Three Area Power System with Artificial Intelligent Controllers," *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*, vol. 6, no. 8, pp. 6576–6591, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[18] Leul Adane, "*An Intelligent Automatic Generation Control for a Hydro-Power System*," AAU, Thesis, 2018. [Publisher Link]

[19] Debdeep S., and Lalit S., "Automatic Generation Control of an Interconnected CCGT-Thermal System Using Stochastic Fractal Search Optimized Classical Controllers," *International Transactions on Electrical Energy Systems*, vol. 28, no. 5, p. e2533, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[20] Indulkar, and Baldev Raj, "Application of Fuzzy Controller to Automatic Generation Control," *Electric Machines and Power System*, vol. 23, no.2, pp. 209-220, 1995. [CrossRef] [Google Scholar] [Publisher Link]

[21] G. Kavita, and Lata Mishra, "Load Frequency and Voltage Control of Two-Area Interconnected Power System using PID Controller," *International Journal of Engineering Technology*, vol. 8, pp. 722-726, 2017. [Google Scholar]

[22] D.K. Sambariya, and N. Vivek, "LFC Using FLC Based for Multi-area Power System," *British Journal of Mathematics & Computer Science*, vol. 13, no. 5, pp. 1-19, 2015.

[23] Ravi Shankar et al., "Fruit Fly Algorithm-Based Agc of Multi-Area Interconnected Power System with Facts and AC/DC Links in Deregulated Power Environment," *International Transactions on Electrical Energy Systems*, vol. 29, no. 1, p. e2690, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[24] Abdullahi B., et al., "Improved Model Predictive Load Frequency Control of Interconnected Power System with Synchronized Automatic Generation Control Loops," *Beni-Suef University Journal of Basic and Applied Sciences*, vol. 9, no. 47, pp. 1-13, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[25] A.P. Srivishnupriya, M Mohamed Thameem Ansari, and N J Vinoth Kumar, "Automatic Generation Control of Three Area Hybrid Power System by Sine Cosine Optimized Dual Mode Fractional Order Controller," *International Journal of Renewable Energy Research*, vol. 12, no. 3, pp. 1415-1426, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[26] Naresh K. Tanwani et al., "Simulation Techniques of Electrical Power System Stability Studies Utilizing MATLAB/Simulink," *International Journal of Engineering Sciences & Research Technology*, vol. 3, no. 3, pp. 1228-1240, 2014. [Google Scholar] [Publisher Link]

[27] Yatin Sharma, and Lalit Chandra Saikia, "Automatic Generation Control of a Multi-Area ST Thermal Power System Using Grey Wolf Optimizer Algorithm Based Classical Controllers," *International Journal of Electrical Power & Energy Systems*, vol. 73, no. 2, pp. 853–862, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[28] Parveen Dabur, Naresh Kumar Yadav, and Vijay Kumar Tayal, "MATLAB Design and Simulation of AGC and AVR for Multi-Area Power System and Demand Side Management," *International Journal of Computer and Electrical Engineering*, vol. 3, pp. 259-264, 2014. [Google Scholar] [Publisher Link]

[29] Amit Panwar; and Sunita Chahar, "Automatic Load Frequency Control of Three Area Power System Using Artificial Intelligence," *International Conference on Micro-Electronics and Telecommunication Engineering*, pp. 320–324, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[30] Suman Machavarapu, Mannam Venu Gopala Rao, and Pulipaka Venkata Ramana Rao, "Design of Load Frequency Controller for Multi-area System Using AI Techniques," *International Information and Engineering Techology Association*, vol. 4, pp. 541-548, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[31] Abhijith Pappachen, and A. Peer Fathima, "Critical Research Areas on Load Frequency Control Issues in a Deregulated Power System: A State-of-the-Art-of-Review," *Renewable and Sustainable Energy Reviews*, vol. 72, pp. 163-177, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[32] Deepesh S., "AGC of Multi-Source Interconnected Power System Using Adaptive Neuro-Fuzzy Inference System," *International Journal of Engineering, Science and Technology,* vol. 12, no. 3, pp. 66-80, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[33] Kaleem Ullah et al., "Automatic Generation Control Strategies in Conventional and Modern Power Systems: A Comprehensive Overview," *Energy*, vol. 14, no. 9, p. 2376, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[34] Gurjit Singh, and Jaspreet Kaur Dhami, "Load Frequency and Voltage Control of Two-Area Interconnected Power System using PID Controller," *International Journal of Engineering Research & Technology,* vol. 4, no.15, pp. 1-4, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[35] Deepesh Sharma, "Load Frequency Control: A Literature Review," *International Journal of Scientific & Technology Research,* vol. 9, no. 2, pp. 6421-6437, 2020. [Google Scholar] [Publisher Link]

[36] S. Kayalvizhi., and D.M Vinod, "Load Frequency Control of an Isolated Micro Grid Using Fuzzy Adaptive Model Predictive Control," *IEEE Access,* vol. 5, pp. 16241-16251, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[37] Zeyad Assi Obaid et al., "Frequency Control of Future Power Systems: Reviewing and Evaluating Challenges and New Control Methods," *Springer,* vol. 7, pp. 9-25, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[38] Sochima Vincent Egoigwe et al., "Application of a Fuzzy Logic Controller for Hydropower Generator Speed Regulation," *European Journal of Engineering and Technology Research*, vol. 4, no. 3, pp. 132-135, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[39] Seyid M., Boobalan S., et al., "Design of Optimal PID Controller for LFC and AVR in Power System using PSO," *International Journal of Advanced Research Trends in Engineering and Technology*, vol. 6, no. 11, 2019. [Google Scholar] [Publisher Link]

[40] R. Ganesan, S. Ramesh, and S. Anbarasi, "A New Literature Review of Automatic Generation Control in Deregulated Environment," *International Journal of Scientific & Technology Research,* vol. 8, no. 12, pp. 2083-2089, 2019. [Publisher Link]

[41] Rishabh Verma, Shalini Palm and Sathans, "Intelligent Automatic Generation Control of Two-Area Hydrothermal Power System Using ANN and Fuzzy Logic," *International Conference on Communication Systems and Network Technologies*, vol. 3, pp. 552-556, 2013. [CrossRef] [Google Scholar] [Publisher Link]

[42] Omveer Singh et al., "A Survey of Recent Automatic Generation Control Strategies in Power Systems," *International Journal of Emerging Trends in Electrical and Electronics*, vol. 7, no. 2, pp. 1-14, 2013. [Google Scholar] [Publisher Link]

[43] T. Shanthi, C.Selvakumar, and S.U.Prabha, "Design of Fuzzy Logic Controller for Speed Control of DC Motor Fed from Solar PV System," *SSRG International Journal of Electrical and Electronics Engineering*, vol. 4, no. 3, pp. 5-9, 2017. [CrossRef] [Google Scholar] [Publisher Link]