A Simple and Novel Tuning Technique for Load Frequency Control in a Multi-Area Microgrid System

Bibhudatta Mishra
Dept. of Electrical Engineering
National Institute of Technology,
Rourkela, India
bibhumishra.123@gmail.com

Raseswari Pradhan
Dept. of Electrical Engineering
VSSUT, Burla
Burla, India
rase1512@gmail.com

Monalisa Pattnaik
Dept. of Electrical Engineering
National Institute of Technology,
Rourkela, India
pattnaikm@nitrkl.ac.in

***Abstract*—A simple and novel analytical tuning technique for load frequency control (LFC) problem is presented in this work. The controllers used in work are conventional fixed parameter PID controllers. Their parameters are evaluated using the most reliable and famous Ziegler-Nichols (ZN) method. The frequencies of each area in a multi-area network as well as the tie-line power get fluctuated due to a slight unexpected load shift in any of the control areas. Further, frequency variations have direct negative influence on the operation, stability, reliability, and efficiency of a power system. Frequency needs to be essentially constant for a power system to operate effectively. Using LFC, an interrelated system can return the frequency of each area and the tie line powers to desired values even with an unexpected load variation. This can be accomplished by usage of a properly tuned controllers like PID controllers. A system model has been constructed in MATLAB/SIMULINK domain. The results from the studied system with ZN-tuned PID controller are compared with that of without PID controller. From the result analysis, the transient performances of studied system with ZN-based PID controller are found to be better than that of without controller case.**

Keywords—LFC, AGC, multi-area power system, PID controller, ZN method

I. INTRODUCTION

A power strategy is an organized network of components that regularly converts natural energy into electrical energy and delivers it from generating sources to loads/users. Power quality plays a vital role in the optimization of power system equipment. Generally, three-phase AC is used for the transmission of electricity due to cost-effectiveness and better efficiency [1]. During the transmission of AC power, the allocation of active and reactive power between the generation and utilisation ends must be maintained. Any changes in either frequency or voltage change the equilibrium point of operation. For a stable electrical power system, the voltage level, as well as frequency, is desired to be maintained constant throughout its operation irrespective of any load variations [2]. A properly designed controller is always required to fulfil this purpose. The control system takes the responsibility of limiting both voltage and frequency variation maintaining the power system operation smooth and reliable [3]. Despite the fact that active and reactive powers combine to affect frequency and voltage, the issues with frequency and voltage management can be divided into two separate ideas. Voltage mostly depends on reactive power, while frequency generally depends on active power. The concept of dependency of real power on the frequency is known as LFC. The highly significant role of LFC is to maintain the frequency invariant in relation to the fluctuating active power demands, often referred to as external disturbances [4]. The system load in the electricity system varies infrequently depending on the needs of the customers. Hence, to regulate system variations and to enhance the stability and reliable functioning of the power system, properly designed controllers are necessary [5]. For this the governor of the generator need to be controlled effectively to handle the scheduled tie-line power. It is essential to update the generation level in each control region periodically for the smooth dynamic operation of the system. As a result, to maintain an equilibrium between overall power generation and consumption, the input mechanical power to specific generating unit in a control region is monitored. This regulating activity is known as Automatic Generation Control (AGC).

When dealing with LFC, the first step is to use the governor to adjust the power system frequency. For the system to be stabilized, this governor control mechanism proved insufficient. Consequently, the governor was given an additional control scheme which incorporates the conventional approach of LFC in the electrical system. To address the limitations of extending the conventional approach, the same frequency is assumed in all areas. The model is developed without considering the variance in frequencies between the control regions. A new rule-based method for tuning PI controller is presented in [6]. Here, the test system is having monotone step responses. The rules of this technique are formulated taking the process dynamics characterization that are collected from experiments.

New tuning guidelines for PI control of processes with essentially monotone step responses, which are frequently found in process control, are presented in [6]. In a small-scale

XXX-X-XXXX-XXXX-X/XX/$XX.00 ©20XX IEEE

PV, wind, and diesel-based power system, the application of the traditional Ziegler-Nichols (ZN) approach for fine-tuning the PID controller parameters is illustrated in [7]. A particle swarm optimized ZN controller is recommended in a PV integrated multi-area network [8]. Lacking in prior information on parameter initial values hinders particle swarm optimization (PSO) methods. The traditional ZN technique, however, does not allow for system speed enhancements. By incorporating PSO, a revitalization of the traditional ZN approach is suggested. This controller helps in enhancing dynamic performance of the system and taking care of its stability as well. In addition, the transient time specifications are settled as per the energy market requirements. The resilience in the suggested scheme is illustrated by taking the system's parametric uncertainty into account. A new method based on artificially intelligent optimization approaches like fuzzy and FOPID is also presented [9]. Fuzzy and model predictive control are used to fine-tune these. In this case, there is a noticeable improvement in the performance of frequency mismatch and peak overshoot and settling time.

A critical analysis of recent AGC approaches is carried out in [9]. It has covered several recent proposed techniques like neural networks and fuzzy logic etc. based techniques. In this article, significant attention is focused on the use of parallel AC/HVDC links in AGC regulator designs. Further, the control techniques are categorized taking accounts some of the essential features.

In [10], a simple fuzzy logic methodology-based controller is developed in MATLAB/SIMULINK environment. The rule of the method is constructed taking the time-varying control error values (e_i) and their respective changes (de_i/dt).

Another approach is also available for a multi-area AGC problem. This method consists of a multiple Power System Stabilizers (PSS) designed with a deregulated context. For availing the deregulation purpose, a parameter called DISCO Participation Matrix (DPM) is introduced here [11].

Several other advanced controllers like ANFIS controller, model predictive control (MPC) based controller, fuzzy PID controller, two-degree-of-freedom-fractional order PID (2-DOF-FOPID) controller are also available in literature [12-15]. Similarly, several artificial tuning techniques are also available like Genetic Algorithm (GA), Firefly Algorithm (FA), Differential Evolution (DE) etc. [16-19].

From all the above discussion and analysis, it is found that PID controller is one of the strong controlling tools used in AGC system. Therefore, there is a lot of scope present in tuning this PID controller. In this context, this work has tried an aged-old but new to this LFC in multi-area AGC type microgrid system.

II. SYSTEM DESCRIPTION AND MODELLING

The majority of power systems now are connected to their nearby regions, rendering the load frequency control (LFC) issue a significant challenge. This section models a typical interconnected two-area power system, with each region represented by the three main elements generator, turbine, and governor. In an electrically connected network, each area is connected with the other area by a tie-line. Each control zone has an LFC loop with a PID controller mounted to manage the deviation in frequency and the tie-line power.

The basic equations representing the studied multi-area system are as follows.

Using the swing equation with small perturbations applicable for a synchronous machine, the Generator Model is mathematically given as follows.

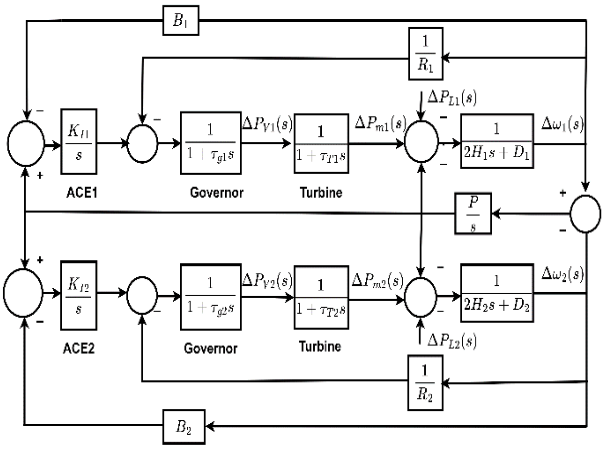


Fig.1. Block diagram of LFC in multi-area AGC type Microgrid System

$$\Delta\omega(s) = \frac{1}{2Hs+D}[\Delta P_m(s) - \Delta P_e(s)] \tag{1}$$

The speed-load characteristic of a composite load can be estimated by

$$\Delta P_e = \Delta P_L + D\Delta\omega(s) \tag{2}$$

where, the terms like $\Delta P_{L,}$ $D,$ $\Delta\omega$ ΔP_m, $\Delta P_{v.}$ and τ_T represent the usual meaning [20]. The ideal form of transfer function for the prime mover model with non-reheat steam turbine having a single time constant τ_T, represented as follows.

$$G_T(s) = \frac{\Delta P_m(s)}{\Delta P_V(s)} = \frac{1}{1+\tau_T s} \tag{3}$$

The speed governor appliance serves as a comparator between the powers ΔP_{ref} and $\frac{1}{R}\Delta\omega$. Then, the governor speed characteristic is executed as follows.

$$\Delta P_g(s) = \Delta P_{ref}(s) - \frac{1}{R}\Delta\omega(s) \tag{4}$$

Here, the signal ΔP_g is produced by the hydraulic amplifier regulating the signal ΔP_v. Assuming a time constant τ_g, the following relation is constructed.

$$\Delta P_V(s) = \frac{1}{1+\tau_g s}\Delta P_g(s) \tag{5}$$

Suppose, there is case where a surplus amount of power in area-1 and it need to feed some amount of power to the area-2 through the tie-line. Then, the real power from area-1 is transported to area-2 under normal operating condition is

$$P_{12} = \frac{E_1 E_2}{X_{12}}\sin(\delta_1 - \delta_2) \tag{6}$$

where, E_1, E_2 and X_{12} are the individual voltage magnitudes of each two areas and series reactance of the interconnected line respectively. The linearized equation for nominal change in tie-line power (ΔP_{12}) can be written as follows.

$$\Delta P_{12} = P_s(\Delta\delta_1 - \Delta\delta_2) \tag{7}$$

where, P_s is synchronizing power coefficient given by

$$P_s = \frac{|V_1||V_2|}{X_{12}}cos(\delta_1 - \delta_2) \tag{8}$$

Therefore, it is demand of today to design an efficient controller that can generate a control signal that can handle intermittent nature of load variation.

III. PROPOSED ZN BASED TUNING METHOD FOR PID CONTROLLER

Although Ziegler-Nichol's (ZN) based tuning technique is not new but it is not tried in this studied system. However, only open-loop tuning concept-based ZN technique is widely used. This paper has proposed a closed-loop tuning method for PID controller that is rarely used as these needs exact knowledge of the system model dynamics. Modelling of a multi-area microgrid system is very complex and never tried before. In this paper, we have formulated a linear transfer function model of this studied system.

In this method, the critical values of gain and time period of oscillation value Kcr and Tcr are used to evaluate the PID controller parameters like K_p, K_i and K_d. It is a age-old but reliable and famous tuning approach. Closed-loop feedback system is used for this method. Here, the Z-N approach that is used for known system dynamics is applied.

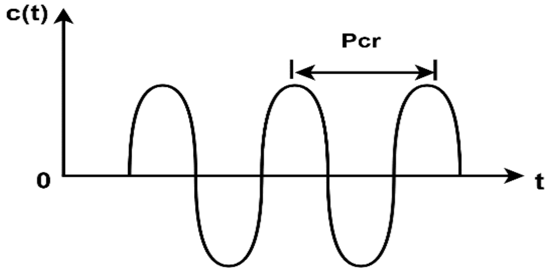


Fig.2. Step response of the multi-area AGC type Microgrid System [14]

To find the values of these parameters and to obtain the tuning constants, the following procedure is followed as shown in Fig. 3.

Step-1: There is no longer an integral or derivative action. Both the derivative controller gains (Kd) and the integral gain (Ki) are set to zero.

Step-2: By altering the set point, the loop experiences a slight perturbation.

Step-3: The proportional gain is modified till the oscillations attain a constant amplitude.

Step-4: The values of Ku and Tu are noted. Then that are incorporated with the closed-loop-feedback equations to set the required controller settings.

Step-5: The critical gain Kcr and the corresponding period Pcr are experimentally determined.

Step-6: Then, the values of the controller parameters are calculated following to the formulae of Table-1.

Fig.3. Procedure of Tuning Algorithm

TABLE I. TUNING RULES USED IN Z-N TECHNIQUE

Type of controller	Control Parameters		
	Kp	Ti	Td
P	0.5 Kcr	∞	0
PI	0.45 Kcr	0.833 Pcr	0
PID	0.5 Kcr	0.5 Pcr	0.125 Pcr

IV. RESULTS AND DISCUSSIONS

A PID Controller is designed and developed for the studied AGC system, using the Z-N criterion. The tuning parameters of the PID controller are found as given in table II. To verify the performance of this controller, a MATLAB/SIMULINK model of the studied system is designed and its respective results are discussed in this section.

TABLE II. PARAMETERS OF STUDIED MULTI-AREA MICROGRID SYSTEM

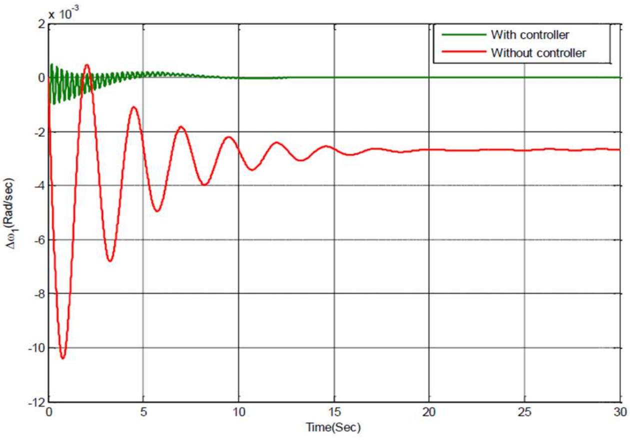
Area-1		Area-2	
System parameters	Value	System parameters	Value
$T_{g1}(s)$	0.2	$T_{g2}(s)$	0.3
$T_{t1}(s)$	0.5	T_{t2} (s)	0.3
H_1 (s)	10	H_2(s)	8
$B1$ (p.u MW/Hz)	20.6	$B2$ (p.u MW/Hz)	16.9
$D1$ (p.u MW/Hz)	0.6	$D2$ (p.u MW/Hz)	0.9
$R1$ (Hz /p.u)	20.6	$R2$ (Hz /p.u)	16.9

Using the tuning algorithm process (Fig. 3) and the rules for tuning parameters of the PID controller (table I) in the multi-area non-reheat microgrid system whose parameters shown in table I, the PID control parameters are calculated as shown in table III.

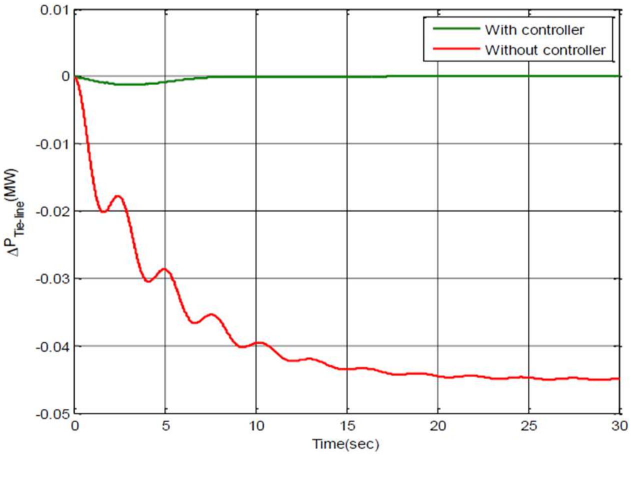
TABLE III. TUNED PARAMETERS OF CONTROLLERS

PID Controllers					
Area-1			Area-2		
Kp	Ti	Td	Kp	Ti	Td
43.75	45.24	95.19	5.33	0.79	80.16

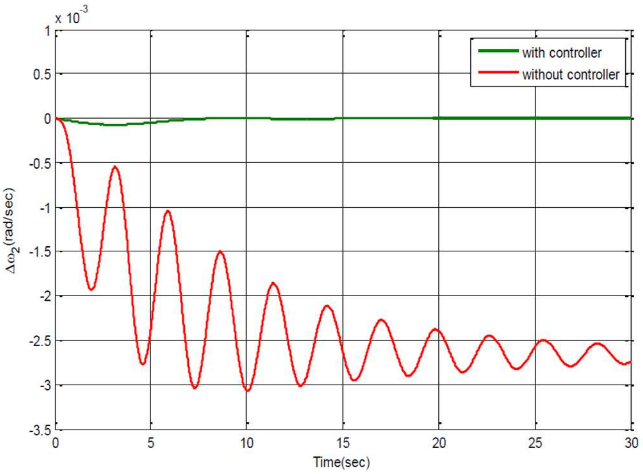
Further, the results such as $\Delta\omega_1$, $\Delta\omega_2$ and ΔP_{Tie} are obtained as depicted in Fig. 4 (a), (b) and (c) respectively. From Fig. 4 (a), different time response characteristics of $\Delta\omega_1$ such as $\%M_p$, T_r, T_p, and T_s are found to be $8.51e5$, $4.78e-6s$, $0.077s$ and $12.03s$ respectively for with controller condition and $2.88e2\ s$, $0.108\ s$, $0.79\ s$, and $16.21\ s$ for without controller condition.



(a)



(b)



(c)

Fig. 4. (a) $\Delta\omega 1$ curve with and without ZN-tuned PID controller, (b) $\Delta\omega 2$ curve with and without ZN-tuned PID controller and (c) ΔP_{Tie} curve with and without ZN-tuned PID controller

From Fig. 4 (b), different time response characteristics of $\Delta w2$ such as $\%M_p$, T_r, T_p, and T_s are found to be $5.93e4$, $0.02\ s$, $3.19\ s$, and $16.93\ s$ respectively for with controller condition and $12.05, 3.54\ s, 10.04\ s$ and $29.08\ s$ for without controller condition. All these time response parameters are tabulated in table IV and table V . The response of change in tie-line power ΔP_{Tie} is depicted in Fig. 4 (c).

TABLE IV. TIME RPONSE SPECIFICATIONS FOR $\Delta\omega_1$

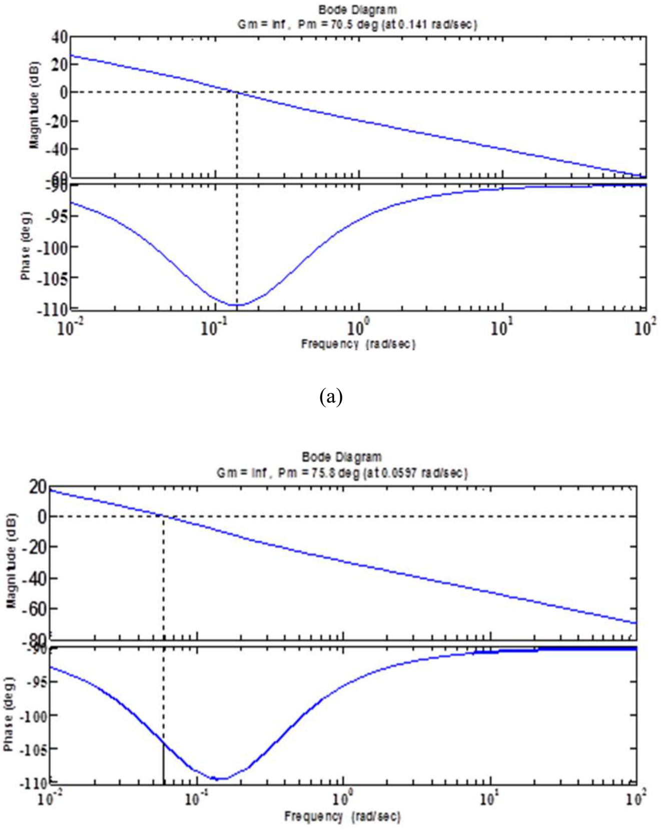
Sl. No.		Control Parameters			
		Mp (%)	Tr (s)	Tp (s)	Ts (s)
1	Without tuned PID	8.51e5	4.78e-6	0.077	12.03
2	With ZN-tuned PID	2.88	0.108	0.79	16.21

TABLE V. TIME RPONSE SPECIFICATIONS FOR $\Delta\omega_2$

Sl. No.		Control Parameters			
		Mp (%)	Tr (s)	Tp (s)	Ts (s)
1	Without tuned PID	5.93e4	3.54	10.04	29.08
2	With ZN-tuned PID	12.05	0.02	3.19	16.93

Again, bode plots for the stability analysis for without and with ZN-tuned PID controller are shown in Fig. 5 (a) and (b) respectively. From the figures, it is clear that system remains stable and gain margin (GM) is infinity in both cases. However, the phase margin (PM) in case of with ZN-tuned PID controller (75.8 deg) is more compared to that of without

ZN-tuned PID controller (70.5 deg). Therefore, the system with ZN-tuned PID controller is more stable.



(a)

(b)

Fig. 5. (a) Bode plot in case of without ZN-tuned PID controller and (b) Bode plot in case of with ZN-tuned PID controller

From the above all discussion, it is observed that the responses with the ZN-tuned PID controller is better than that of the PID controller without ZN tuning.

V. CONCLUSION

A model of two non-reheat interconnected power systems has been studied without and with PID controller conditions. For the system, the Ziegler-Nichols tuning method is implemented to study the characteristic criteria. A block diagram model has been constructed in MATLAB/SIMULINK domain. Different time response characteristics such as the maximum overshoot, rise time, peak time, and settling time of each area are analyzed with the proposed PID controller. Finally, it is observed that the two-area system gives better performance with the use of a tuned PID controller. Due to their ease of implementation and tuning, PID controllers are frequently used in power and control systems to reduce steady-state error, dampen system oscillations, and boost stability. With the Zeigler Nichols technique, the PID controller are tuned to handle a variety of disturbances. A microgrid with a PID controller simulates with adequate dynamic performance and no steady state error. In this power system model, the system frequency is brought back to its desired value with acceptable tolerance, enabling the fastest restoration of tie-line power.

REFERENCES

[1] I. Petri, A. Alzahrani, J. Reynolds, and Y. Rezgui, “Federating smart cluster energy grids for peer-to-peer energy sharing and trading”, IEEE Access, Vol. 8, pp.102419-102435, 2020.

[2] M.T.L. Gayatri, A.M. Parimi, and A.P. Kumar, “A review of reactive power compensation techniques in microgrids”, Renewable and Sustainable Energy Reviews, Vol. 81, pp.1030-1036, 2018.

[3] R. Kaluthanthrige, and A. D. Rajapakse, “Evaluation of hierarchical controls to manage power, energy and daily operation of remote off-grid power systems”, Applied Energy, Vol. 299, p.117259, 2021.

[4] C. Zhang, S. Wang, and Q. Zhao, “Distributed economic MPC for LFC of multi-area power system with wind power plants in power market environment”, International Journal of Electrical Power & Energy Systems, Vol.126, p.106548, 2021.

[5] Wen Ten, “Unified Tuning of PID Load Frequency Controller for Power Systems via IMC”, IEEE Transactions on Power Systems, Vol. 25, No. 1, pp. 341-350, 2010.

[6] T. Hägglund, and K. J. Åström, "Revisiting the Ziegler-Nichols tuning rules for PI control", Asian Journal of Control, Vol.4, no. 4, pp. 364-380, 2002.

[7] P. Kumar, and D. P. Kothari, "Recent philosophies of automatic generation control strategies in power systems", IEEE transactions on power systems, Vol. 20, no. 1, pp. 346-357, 2005.

[8] I. H. Altas, and A. M. Sharaf, "A generalized direct approach for designing fuzzy logic controllers in Matlab/Simulink GUI environment", International journal of information technology and intelligent computing, Vol. 1, no. 4, pp. 1-27, 2007.

[9] T. Mohammed, J. Momoh, and A. Shukla, "Single area load frequency control using fuzzy-tuned PI controller", *North American Power Symposium (NAPS)*, pp. 1-6. IEEE, 2017.

[10] M. I. Alomoush, "Load frequency control and automatic generation control using fractional-order controllers", *Electrical Engineering*, Vol. 91, no. 7, pp. 357-368, 2010.

[11] R. Pradhan, and S. Panda, "Application of Genetic Algorithm based PSS for two-area AGC system in a deregulated scenario", World Congress on Nature & Biologically Inspired Computing (NaBIC), pp. 1207-1212. IEEE, 2009.

[12] W. Eshetu, P. Sharma, and C. Sharma, “ANFIS based load frequency control in an isolated micro grid”, IEEE international conference on industrial technology (ICIT), pp. 1165-1170, 2018.

[13] D.H. Tungadio, and Y. Sun, “Load frequency controllers considering renewable energy integration in power system”, Energy Reports, Vol. 5, pp.436-453, 2019.

[14] M. M. Gulzar, M. Iqbal, S. Shahzad, H. A. Muqeet, M. Shahzad, and M. M. Hussain, “Load Frequency Control (LFC) Strategies in Renewable Energy-Based Hybrid Power Systems: A Review”, Energies, Vol. 15, no. 10, p.3488, 2022.

[15] G. T. Subham, R. Ramachandran, J. Kandasamy, and R. Muralidharan, “Automatic Load Frequency Control of Renewable Energy Integrated Hybrid Power System”, Journal of Trends in Computer Science and Smart Technology, Vol. 4, no. 1, pp.10-16, 2022.

[16] S. R. Khuntia, and S. Panda, "Simulation study for automatic generation control of a multi-area power system by ANFIS approach", Applied soft computing, Vol. 12, no. 1, pp. 333-341, 2012.

[17] U. Sarma, and L.C. Saikia, “Application of Firefly Algorithm Optimized Fuzzy 2DOFPID Controller for Diverse-Sourced Multi-area LFC. In Computing Algorithms with Applications in

Engineering", pp. 261-267, Springer, Singapore, 2020.

[18] P. C. Pradhan, R. K. Sahu, and S. Panda, "Firefly algorithm optimized fuzzy PID controller for AGC of multi-area multi-source power systems with UPFC and SMEs", Engineering Science and Technology, an International Journal, Vol. 19, no. 1 pp. 338-354, 2017.

[19] S. K. Pandey, S. R. Mohanty, and N. Kishor, "A literature survey on load–frequency control for conventional and distribution generation power systems", Renewable and Sustainable Energy Reviews, Vol. 25, pp. 318-334, 2013.

[20] R. Pradhan, and D. Mohanty. "A comparative study of different controllers in a deregulated MAMM system", Technologies for Smart-City Energy Security and Power (ICSESP), pp. 1-6. IEEE, 2018.

.