Automatic Generation Control Using Model Reference Adaptive Control (MRAC) Scheme in a Single Area Power System

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Abstract:

This study illustrates the application of the Model Reference Adaptive Control (MRAC) Scheme for Automatic Generation Control (AGC) in a single area power system. For AGC issues, a type of adaptive control called the MRAC scheme is used. In this MRAC, the generating unit's output or states are employed to mimic a reference model that has been specifically chosen and is intended to have favorable performance characteristics. The Lyapunov stability criteria serve as the foundation for the adaptive control legislation. A single area power system is seen as an illustration of the potential of the suggested strategy. The system is considered to be sensitive to bounded disturbance and to have unknown but constant parameters that take values inside of a predetermined bounded range. The adaptive control rule's ability to guarantee that the controller parameters are restricted and that the tracking error among the system and the reference model is asymptotically stable is established. The comparison between the proposed MRAC controller and the fixed gain conventional PID controller adjusted using Ziegler-Nichol's rule-based tuning and Astrom-Hugglund's tuning rule is demonstrated by the results. In comparison to the conventional one, the MRAC adaptive controller performs better in terms of undershoot and settling time.

***Key words**: Automatic Generation Control; MRAC; Lyapunov Stability; Single Area Power System.*
DOI Number: 10.48047/nq.2021.19.3.NQ21036 NeuroQuantology 2021; 19(3): 1187-1197

1. Introduction

Due to interruptions from time-varying loads or network changes, operating conditions for power systems are always changing. Changes in the kinetic energy of spinning inertias of generators and motors are the main method used to counter temporary disturbances. Frequency sensitive loads will be impacted by any frequency changes. If the equilibrium is attained, the frequency change will stop in a few seconds at a new system frequency. The secondary control comes next from the AGC of the control regions, which will work together to try and regulate its generation to return the system frequency to its nominal value.

Second, the governor will adjust the output power of the producing unit if the system frequency exceeds the governor dead-band. This can be accomplished with the aid of governor speed droop, which is the governor's feedback loop gain. The basic control action for typical disturbances is to stop the frequency deviation from moving to a new frequency above or below the nominal value. The secondary control then brings the frequency back to its original value. Both human and automatic follow-up control actions are possible. The Automatic Generation Control (AGC) is the common name for an automatic secondary control [1, 7, 8].

The power system is sophisticated and intricate, with numerous compartments and power sources. For power regulation within its specified restricted area, nominal system frequency and tie line power exchange are required. The AGC is essential to the power pool because it maintains the system's periodic frequency, periodic tie-line energy, and small load disturbances.Many investigations regarding the application of AGC to single area power system have been reported over the past years. To improve dynamic performance, many control strategies have been used in the design of the AGC controller. The standard PI controller is the sort of AGC controller that is most frequently used. Although the PI controller is easy to construct, it typically results in significant frequency variations.

Fixed gain controllers are unable to deliver the optimal control performance under a variety of operating situations because they are designed to work at nominal operating conditions. Therefore, it is desired to track the operating circumstances and use the updated parameters to compute the regulated input in order to maintain system performance close to its maximum. For dealing with significant parameter fluctuations, many methods of adaptive control have been developed. Making the process under control less sensitive to changes in process parameters and to unmodeled dynamics is the goal of adaptive control.

In this study, a controller for a single area system is created using Model Reference Adaptive Control (MRAC). Utilizing the adaptive gain control technique described in sections 2 and 3 to achieve zero steady state error; MRAC has been tested for a variety of load disturbances. To show the universal applicability, simulation results are shown with comparisons [2,3,4,5,6,8].

2. Model Reference Adaptive Control

Model reference control is to ensure that the output of a managed system reflects the output of a certain reference model in as well as preserving closed-loop stability [9,10,11]. Adaptive rules are created to modify a controller's configurations in order to deliver the required output when the plant's parameters are unknown.This plan specifies the desired control objectives using the output of the reference model. The design problem must be solved in a way that the discrepancy between plant and model outputs simultaneously approaches zero. Based on prior settings of the controller parameters and control inputs, this necessitates the adaption of the controller parameters. The output of the plant deviates from the intended trajectory, which is represented by the tracking error. The closed-loop plant comprises of an output feedback controller and a modification system that allows changing the controller's parameters.The controllers are often built with certain operating circumstances and predetermined system characteristics in mind. The performance of the controller might not be at its best when operating conditions, system parameters, or both, vary. The controller must be created to update its parameters to track any type of modification in order to work at its best, or it must be adaptive and self-tuning.

The key problems are stability analysis, minimum prior plant information, controller parameterization, error model derivation, adaptive law design, and adaptive law design [12,13,14,15,16].Figure 1 depicts the MRAC scheme's fundamental elements.

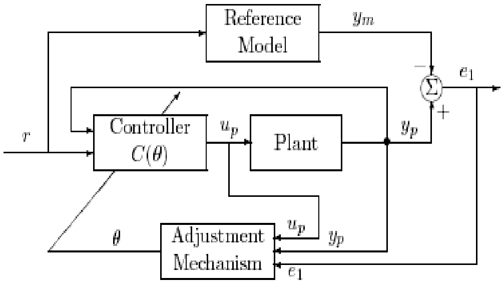

Figure 1: Basic elements of the MRAC system

3. Design of MRAC for LTI SISO System [17-24]

3.1 Plant Model

Consider the following example of an unknown, single-input, single-output, linear time-invariant plant:

$$G_p(s) = k_p \frac{Z_p(s)}{R_p(s)} \tag{1}$$

or in the equivalent state space form as

$$\begin{aligned} \dot{x}_p &= A_p x_p + B_p u_p, x_p(0) = x_0 \\ y_p &= C_p^T x_p \end{aligned} \tag{2}$$

where $x_p \in R^n; y_p, u_p \in R^1$ and A_p, B_p, C_p have the suitable dimensions. Z_p, R_p are the monic polynomials and k_p is a constant referred to as the High Frequency Gain (HFG). The plant model must adhere to the underlying presumptions in order to achieve the MRAC aim.

1. $Z_p(s)$ is a Monic Hurwitz polynomial of degree m_p.

2. An upper bound n of the degree n_p of $R_p(s)$.

3. The relative degree $n^* = n_p - m_p$ of $G_p(s)$, and

4. The high frequency gain k_p sign has been determined.

3.2 Reference Model [17,18,19]

Finding a direct controller without differentiators is the goal of the control system, and the output of the plant should resemble that of the predetermined reference model. The selected model has the form of

$$W_m(s) = k_m \frac{Z_m(s)}{R_m(s)} \tag{3}$$

where $Z_m(s), R_m(s)$ are monic polynomials, k_m is constant gain and r is the reference input supposed to be a piecewise continuous, uniformly bounded function of time.

3.3 Controller Structure

The controller structure is set up to adhere to the aforementioned requirements as follows:

$$u(t) = \theta_1^T(t)\frac{\alpha(s)}{\Lambda(s)}u + \theta_2^T(t)\frac{\alpha(s)}{\Lambda(s)}y_p + \theta_0(t)y_p + c_0 r \qquad (4)$$

$$\theta^*(t) = [\theta^{*T}_1(t), \theta^{*T}_2(t), \theta^*_0(t), c_0^*]^T \qquad (5)$$

where $\alpha(s) = [s^{n-2}, s^{n-3}, ..., s, 1]^T$; for n>=2

$\alpha(s) = 0$; for n=1

Where$Z_m(s)$ is a factor in $\Lambda(s)$, a monic Hurwitz polynomial of degree n-1 that can be chosen at will.

$\Lambda(s) = \Lambda_0(s)Z_m(s)$

Which indicates that $\Lambda_0(s)$ is monic, Hurwitz and of degree n_0=n-1-q_m. The transfer function from r to $y_p$mustmatches to $W_m(s)$ for the controller parameter vector to be picked. The transfer equation represents the closed loop plant's I/O characteristics.

$$y_p(s) = G_c(s).r(s) \qquad (6)$$

Since the closed loop transfer function $G_c(s) = W_m(s)$ has been realized and the closed loop poles are stable, we may achieve the control aim by choosing the controller parameters.

4. Automatic Generation Control: Single Area System

In order to keep the scheduled frequency, AGC is taken into account in this study for a single generator supplying electricity to a local service area (isolated load). To retain their relative power angles as they accelerate and decelerate all the generators in this area cooperate closely. 'Control Area' is the term used to describe such a region. Maintenance of the power exchange is not a problem in a disconnected power system [1,7].

5. Model Description

It is feasible to generate a detailed block diagram description of an isolated power system comprised of a turbine, generator, governor, and load through integrating the block diagrams of the individual components.

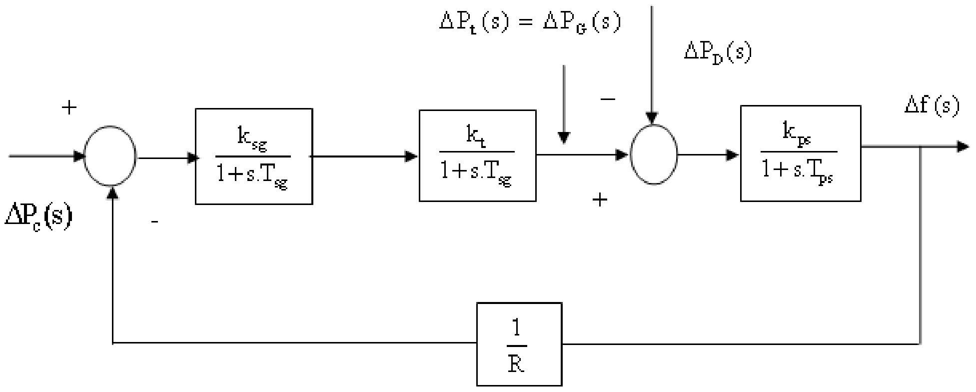

Figure 2 : Block diagram of isolated power system

6. State Space Model of Single Area System

Electric power systems' actual models are typically nonlinear. The control schemes, however, are designed using the linearized model for load frequency management. The single area power system's dynamic model can be expressed as follows:

$$\dot{x} = Ax(t) + Bu(t) + Fw(t)$$

$$y(t) = Cx(t)$$

where $x(t) = \begin{bmatrix} \Delta f & \Delta P_t & \Delta X_g & \Delta P_c \end{bmatrix}^T$

$$u(t) = \begin{bmatrix} 0 & 0 & \Delta P_c & 0 \end{bmatrix}, w(t) = [\Delta P_D \quad 0 \quad 0 \quad 0], y = [\Delta f \quad 0 \quad 0 \quad 0]$$

$$A = \begin{bmatrix} -\frac{1}{T_{ps}} & \frac{k_{ps}}{T_{ps}} & 0 & 0 \\ 0 & -\frac{1}{T_t} & \frac{1}{T_t} & 0 \\ -\frac{1}{R.T_{sg}} & 0 & -\frac{1}{T_{sg}} & -\frac{1}{T_{sg}} \\ K_i & 0 & 0 & 0 \end{bmatrix}, B = \begin{bmatrix} 0 & 0 & \frac{1}{T_{sg}} & 0 \end{bmatrix}^T, F = \begin{bmatrix} \frac{k_{ps}}{T_{ps}} & 0 & 0 & 0 \end{bmatrix}^T$$

$$C = \begin{bmatrix} 1 & 0 & 0 & 0 \end{bmatrix}$$

Assumption: It is assumed that the disturbance $w(t)$ is bounded, i.e. there exists a known scalar d_1 such that $\|w(t)\| \le d_1$ [19].

7. Choice of Reference Model

In the design of MRAC the reference model is chosen as per assumption made in the section 3.2.For the load frequency control the following transfer function is chosen as the reference model. All the desired specification has been incorporated in the model. The specifications are given below, which are explicit from the response shown in figure3.

$$W_m(s) = k_m \frac{Z_m(s)}{R_m(s)} \quad (7)$$

$$W_m(s) = \frac{-500s}{s^4 + 24.18s^3 + 221.46s^2 + 1174.7s + 3782.25} \quad (8)$$

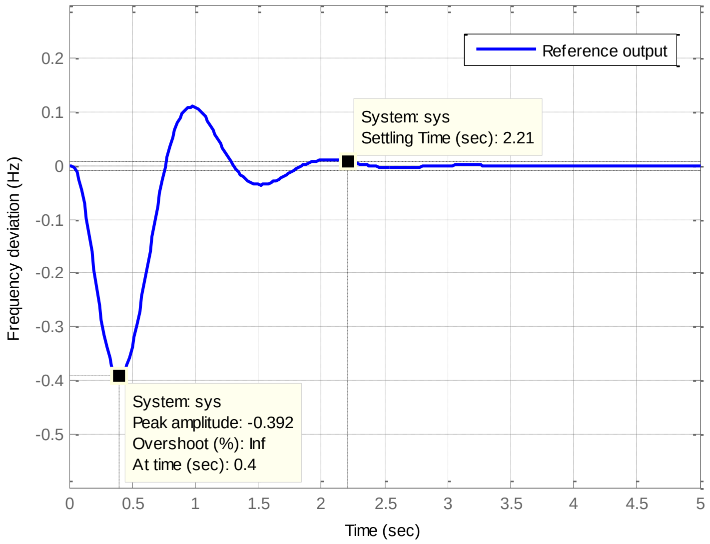

Figure 3 : Reference Model Output

8. Ziegler -Nichols Rule Based Tuning

The PID controller was tuned using Ziegler-Nichols tuning rule as a comparison [20]. This method of tuning is known as a closed loop tuning strategy since the controller stays in the loop as an active controller in automated mode. After being the process reaches steady state at the normal level of operation, turns off the integral and derivative controller modes and only uses the proportional controller. Choosing a proportional gain, upsetting the system, and keeping an eye on the transitory response.If the reaction falls off, choose a greater gain value. Continue gradually raising the gain until the answer first demonstrates sustained oscillations. The maximum gain (K_u) and the maximum period (P_u) are the value of the gain and the period of oscillation that correlate to the sustained oscillation, respectively.

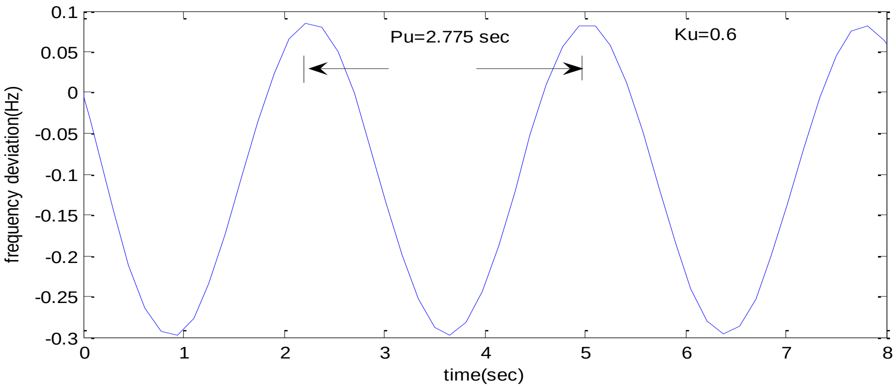

Figure 4: System response with proportional controller under critical gain

Table 1: Controller Parameters (Z-N Tuning Rule)

Controller	K_c	T_i	T_d
PI	$0.45.K_u=0.27$	$P_u/1.2=2.3125$	-

PID	$0.6.K_u$=0.36	$P_u/2$=1.3875	$P_u/8$=0.3469

9. Astrom-Hagglund (A-H) Rule Based Tuning

The Astrom-Hagglund tuning rule, which is depends on the critical gain and critical period identified from sustained oscillations [20], is also used to derive the PID controller's parameters. The tuning parameters are based on the criteria of having gain margin of 24.76 dB and phase margin of 46^0. This rule gives the tuning rule for the ideal PID controller for non-model specific system. The tuning rules are given in Table2.

Table 2: Controller Parameters (A-H Tuning Rule)

Controller	K_c	T_i	T_d
PID	$0.2015.K_u$=0.1209	$0.7878.P_u$=2.1861	$0.197.P_u$=0.5466

10. Simulation and Results

The load frequency issue of a single area power system is addressed by the proposed MRAC control method. The performance of conventional PI, PID and MRAC controllers are compared for the same system. The MATLAB/Simulink package has been used in the simulations. The power system's specifications are listed below [25].

T_{sg}= 0.4 seconds ; T_t= 0.5 seconds ;
T_{ps} = 20 seconds ;k_{sg}= k_t= 1 ;k_{ps}= 100 ; R = 3 Hz/pu MW.

Simulations are conducted for two different values of load disturbances. In first case system is simulated for 30 seconds with a step load disturbance of 0.1 pu at t=5 sec.In second case the load disturbance of 0.2 pu is tested. Figures 5 and 6 show the time domain performance for frequency deviation and control input respectively. Figure 7 shows the plot for controller parameters of MRAC controller for load disturbance of 0.1 pu.

The conventional controllers are tuned based on Ziegler –Nichols rule and Astrom-Hugglund tuning rule as discussed in sections8 and 9. The MRAC controller is simulated for the adaptation gain of 0.5.As the load disturbance is applied at t = 5 s of 0.1 pu the governor setting automatically adjusts to 0.1 pu to meet the load demand, thereby the scheduled frequency is maintained. As perfect tracking takes place, the controller parameters attains to their steady values i.e. [0.0998 -0.0022 -0.0012 0.0031].

Also the load disturbance of 0.2 pu is applied at t = 5 sec. to demonstrate the effectiveness of the scheme proposed. The value of the controller parameter after adaptation is [0.1987 -0.0083 -0.0047 0.0125].Performance of the controller for disturbance of 0.2 pu is presented in Table 4.

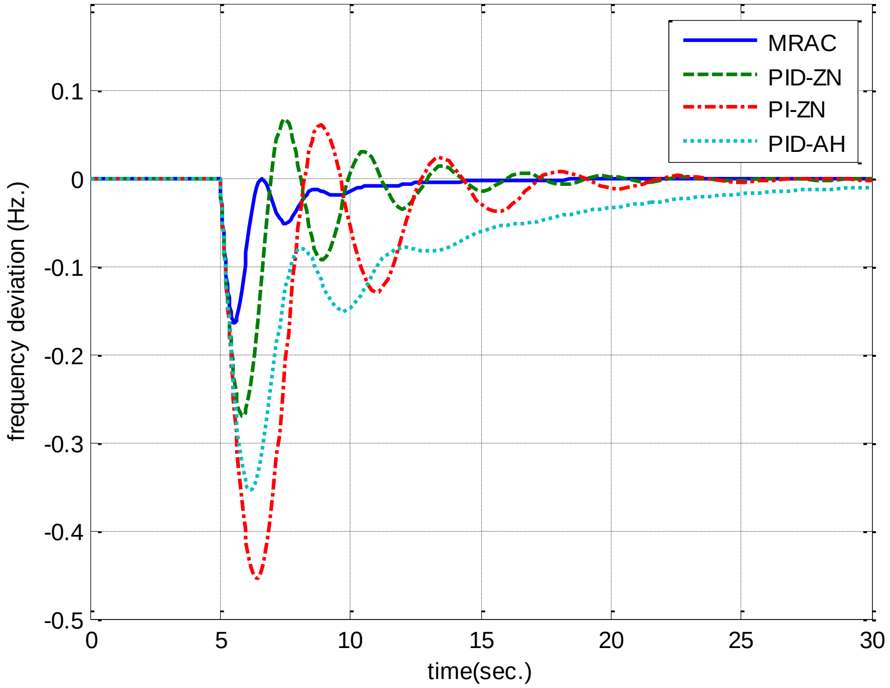

Figure 5 : Variation of frequency due to step change in load (0.1 pu).

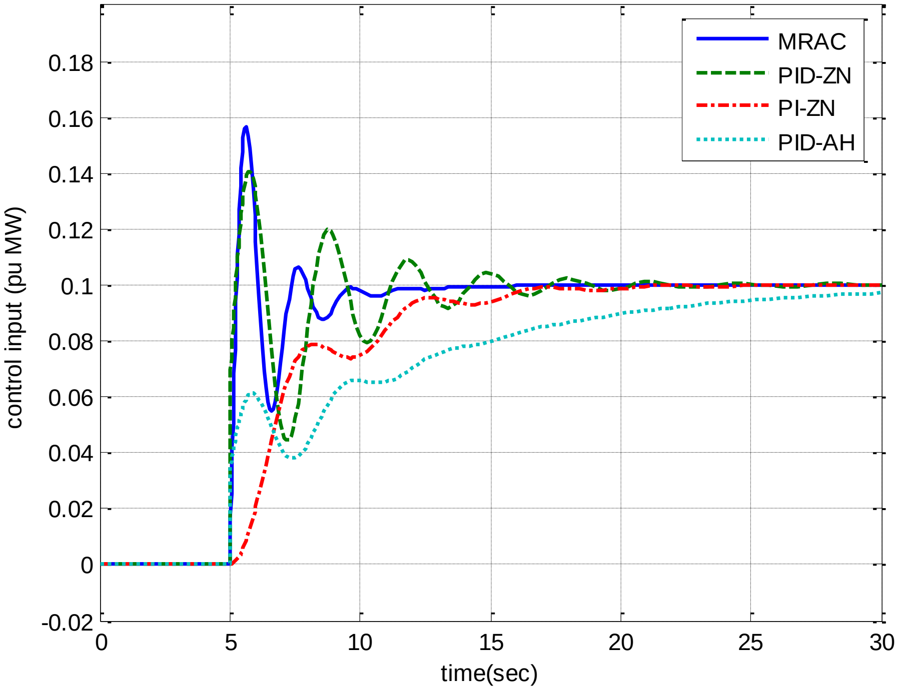

Figure 6: Control input (governor speed changer setting).

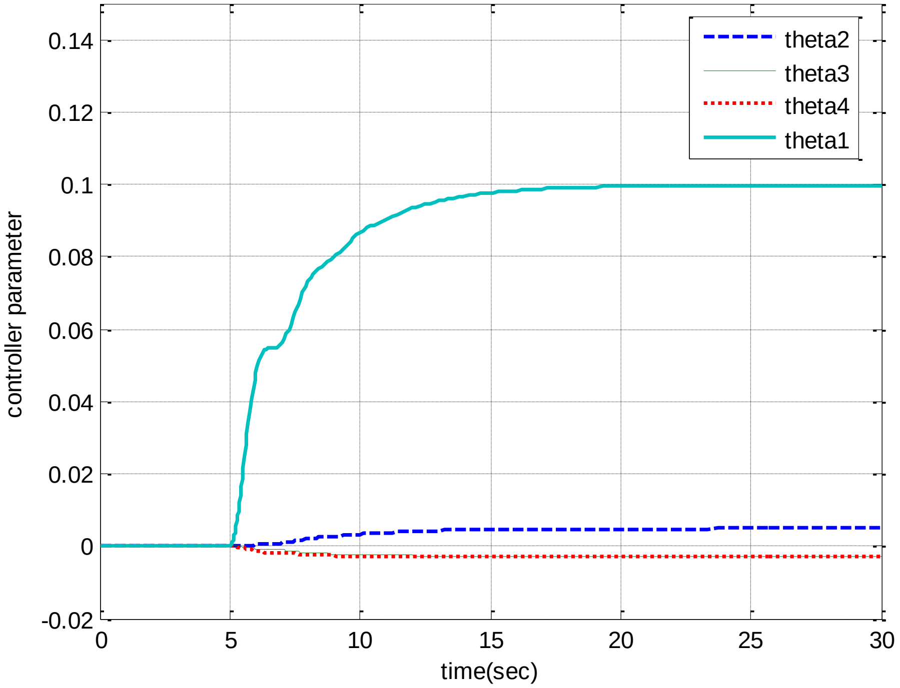

Figure 7 : Controller parameter (0.1 pu).

Table 3 : Comparison for Single Area Results (0.1 pu)

Controller	Undershoot (Hz)	Settling time (sec)
PI	-0.4541	25
PID(Ziegler-Nichols)	-0.2695	16
PID(Astrom&Hugglund)	-0.3530	More than 20 sec.
MRAC	-0.1382	6

Table 4: Comparison for Single Area Results (0.2 pu)

Controller	Undershoot (Hz)	Settling time (sec)
PI	-0.9080	25
PID(Ziegler-Nichols)	-0.5390	16
PID (Astrom-Hugglund)	-0.7064	More than 20 sec.
MRAC	-0.2765	6

11. Conclusion

The MRAC adaptive controller operates more effectively in terms of undershoot and settling time, according to the simulation findings. For the load disturbance of 0.1 pu the undershoot is less for MRAC controller as compared to conventional PID controllers. For the load disturbance of 0.2 pu, the settling time is same, only the increased undershoot is observed that is within the acceptable limit. The undershoot in frequency is much smaller for MRAC scheme than conventional controllers. Also the control input produced by MRAC controller is within acceptable limit. According to simulation results, the suggested MRAC controller may successfully achieve good dynamic performance for the example system even in the presence of a variety of load disturbances.

References

[1] Elgerd O.I., Electric Energy Systems Theory: An Introduction, McGraw-Hill, TMH Edition, 1971.

[2] Vajk I., M. Vajta, and L. Keviczky, “Adaptive load frequency control of Hungarian power system”, Automatica, vol. 21, no. 2, pp. 129–137, 1985.

[3] Pan C.T. &Liaw C.M., “An Adaptive Controller for Power System Load-Frequency Control”, IEEE Transactions on Power Systems, Vol.4, No.1, February, 1989.

[4]Wan, Yong, and Federico Milano. "Nonlinear adaptive excitation control for structure preserving power systems." IEEE Transactions on Power Systems 33, no. 3 (2017): 3107-3117.

[5] Yousef H. and Simman M.A., “Model reference adaptive control for large scale systems with application to power systems”, IEE Proceedings, Vol. 138, No. 4.July 1991.

[6]Dahab, Yasser Ahmed, Hussein Abubakr, and Tarek Hassan Mohamed. "Adaptive load frequency control of power systems using electro-search optimization supported by the balloon effect." IEEE access 8 (2020): 7408-7422.

[7] NagrathI.J.and Kothari D.P., Modern Power System Analysis, Tata McGraw Hill Publishing Company, New Delhi, 2000.

[8] Ibraheem, Prabhat Kumar and Kothari D.P. “Recent philosophies of an Automatic Generation Control strategies in power systems”, IEEE Transactions on power systems, Vol. 20.No.1, February 2005.

[9] Parks P.C., “Lyapunov Redesign of MRAC systems”, IEEE Transactions onAutomaticControl,vol.11, pp.362-367, 1966.

[10] Sun, Jing. "Model reference adaptive control." In *Encyclopedia of Systems and Control*, pp. 1252-1256. Cham: Springer International Publishing, 2021.

[11] Landau I.D., “A Hyper stability criterion for Model Reference adaptive control systems”, IEEE Transactions on Automatic Control, vol.14, pp.552-555, 1969.

[12] Petras A.Ioannou and Kostas S. Tsakalis, “A Robust Adaptive Controller” IEEE Transactions on automatic control.vol.AC-31.no.11, 1986.

[13] Kreisselmeier. G and Anderson B.D.O., “ Robust Model Reference Adaptive Control”, IEEE Transactions on Automatic Control,vol.31, no.2, pp127-133, 1986.

[14] GrahmC.Goodwin& David Q.Mayne, “Continuous Time Stochastic Model reference Adaptive Control”, IEEE Transactions on automatic control, Vol. 36, No.11, November 1991.

[15] Jing Sun, “A Modified Model Reference Adaptive Control Scheme for Improved Transient Performance”, IEEE transaction on Automatic control, vol.38.no.8, August 1993.

[16] DattaAniruddha and Ming-Tzu Ho, “On Modifying Model Reference Adaptive control schemes for performance improvement”, IEEE Transaction on automatic control, vol.39, no.9, September 1994.

[17] Karl J. Astrom, Bjorn Wittenmark, Adaptive control,II edition, Pearson Education, 1995

[18] Karl J. Astrom, Bjorn Wittenmark, “A survey of adaptive control applications, Conference on decision and control”, December 1995.

[19] Ioannou P.A. and Sun J., Robust Adaptive Control, Prentice-Hall, Upper Saddle River, NJ, 1996.

[20] Astrom, K.J. and Hugglund, T. PID Controllers: Theory, Design and Tuning (Instrument Society of America, Research Triangle, Park North Carolina, 2nd Edition, 1995.

[21] Vehram Stepanyan and Kalmanje Krishnakumar, " Adaptive Control with Reference Model Modification", Journal of Guidance, Control and Dynamics, Vol. 35, No. 4, July-August 2012.

[22] Norelys Aguila-Camacho and Manuel A. Duarte-Mermound, Senior Member, IEEE "Improving the Control Energy in Model Reference Adaptive Controllers Using Fractional Adaptive Laws" IEEE/CAA Journal of Automatica Sinica, Vol. 3, No. 3, July 2016.

[23] Geo Song, Student Member, IEEE, Gang Tao,Fellow, IEEE " A Partial-State Feedback Model Reference Adaptive Control Scheme" 0018-9286(c), 2018 IEEE.

[24] Gang Tao, Fellow, IEEE, and Ge Song, Student Member, IEEE " Higher Order Tracking Properties of Model Reference Adaptive Control Systems" IEEE Transactions on Automatic Control, 0018-9286(c), 2018 IEEE.

[25] RavindraSingh,IndraneelSen, "Tuning of PID Controller Based AGC System Using Genetic Algorithms" ,IEEE Proceedings,0-7803-8560-8/04,2004.