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

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Abstract

This paper describes the application of Model Reference Adaptive Control (MRAC) for load frequency control (LFC) in multiarea power system. For LFCproblem, one of the MIMO adaptive control strategy called Decentralized Adaptive Control is used. In this scheme the output or the states of the generating unit are to track those of an explicitly specified reference model which is designed to have desirable performance characteristics. The adaptive control law is derived from Lyapunov stability criteria. A two area reheat thermal power system is considered to exemplify the potential of proposed approach. It is assumed that the system is subjected to bounded disturbance and is characterized by unknown but constant parameters which take values within a known bounded range. Conditions are determined under which the adaptive control law guarantees boundedness of controller parameters and ensures asymptotic stability of the tracking error between the system and the model. The results reported in this paper demonstrate the effectiveness of the proposed controller over the fixed gain conventional controller.

Key words: Adaptive Load Frequency Control; MRAC; Lyapunov Stability; Multi Area Power Systems
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I. Introduction

Many investigations in the area of LFC problem of interconnected power systems have been reported over the years**[2,4,6,7,8,9,10,11,15,18].**A number of control strategies have been employed in the design of load frequency controllers in order to achieve better dynamic performance. Among the various types of load frequency controllers, the most widely employed is the conventional proportional integral controller. The PI controller is simple for implementation but generally results in large frequency deviations. Fixed gain controllers are designed at nominal operating conditions and fail to provide best control performance over a wide range of operating conditions. So, to keep the system performance near its optimum, it is desirable to track the operating conditions and use updated parameters to compute the controlled input. In view of this various adaptive control techniques have been proposed for dealing with large parameter variations. Mainly, adaptive control schemes can be classified into two categories, namely the **self tuning regulators** and **model reference adaptive control** systems **[13, 14]**. The task of adaptive control is to make the process under control less sensitive to changes in process parameters and to un-modeled dynamics.

Application of adaptive control theory to large scale system is reported in 1986.In **[3]** the results for global stability of a decentralized model reference adaptive control for an interconnected system with an arbitrary interconnection of subsystem and characterized by unknown parameters, nonlinearities and boundedness is established. In**[5]**structural stability conditions for decentralized adaptive control of system with known subsystem but with unknown interconnection are established. The stability of entire adaptive system is analysed using Lyapunov approach.

Large-scale power systems are normally composed of interconnected subsystems or control areas. The connection between the control areas is established using tie lines. Each area has its own generator or group of generators and are responsible for its own load and scheduled interchanges with neighboring areas. Because loading on a power system is never constant and to ensure the quality of power supply, a load frequency controller (LFC) is needed to maintain the system frequency at the nominal value. It is known that changes in real power affect mainly the system frequency and the input mechanical power to generators is used to control the frequency of the output electrical power **[1, 16].**

In this work decentralized MRAC scheme is used for LFC of the multiarea system. Decentralized adaptive control scheme is one of the multi input multi output MRAC scheme. More specifically, a two area interconnected system is characterized by known parameters, which takes values within a bounded range, and are subjected to bounded constant disturbances are considered. The main problem with a decentralized LFC is that the interactions are treated as disturbances. Because two subsystems (areas) are located distantly, it is difficult for a centralized controller to gather feedback signals from these subsystems. Also the design and implementation of the centralized controller are complicated. Therefore decentralized controllers, designed independently for local areas and using local available signals for feedback. Its design procedure is same as that in scalar case. However, such decentralized controllers should be robust against the ignored interactions. [**12]**

The state-of-art of LFC is based on the generally accepted concept of tie-line frequency bias in multi area system. It is defined by the Area Control Error (ACE).ACE represents the mismatch between area load and generation taking into account any energy interchange agreement with neighboring areas. Until ACE is brought to zero, the system frequency and net interchange will remain off schedule. The fundamental composition of ACE is described by the equations.

$$ACE_i = \Delta P_{tie,i} + b_i.\Delta f_i \quad (1)$$

$$\Delta P_{tie,i} = P_{tie,i(actual)} - P_{tie,i(sceduled)} \quad (2)$$

$$\Delta f_i = f_{i,actual} - f_{i,scheduled} \quad (3)$$

Where b_i is referred to as tie-line frequency bias and represents an approximation of the area response to frequency deviations.Sothat, in order to bring the system conditions back to schedule, ACE is processed as control signal for regulation purpose.

The paper is organized as follows. In section II the concept of decentralized adaptive control is discussed and in section III the model description has been explained in brief. In section IV the selection of reference model for AGC problem is given along with reference model trajectory specifying the desired specifications. In section V & VI PID controller parameter are tuned using Ziegler-Nichol's and genetic algorithm respectively. The effectiveness of the proposed scheme is demonstrated using a two area power system.

II. Decentralized Adaptive Control [1, 4, 12]

Let us consider the MIMO plant model

$$y = H(s).u \quad (4)$$

where $y \in R^N, u \in R^N$ and $H(s)$ is the $N \times N$ plant transfer matrix that is assumed to be proper. Equation (4) may be also expressed as

$y_i = h_{ii}(s).u_i + \sum_{\substack{1\le j\le N \\ j\ne i}} h_{ij}(s).u_j, i = 1, 2, ..., N$ (5) where $h_{ij}(s)$,the elements of H(s), are transfer functions.

Another more general decomposition of (5) is

$y_i = h_{ii}(s).u_i + \sum_{\substack{1\le j\le N \\ j\ne i}} (h_{ij}(s).u_j + q_{ij}(s).y_j), i = 1, 2, ..., N(s)$

(6)

for some different transfer functions $h_{ij}(s), q_{ij}(s)$.If the MIMO plant model (6) is such that the interconnecting or coupling transfer functions $h_{ij}(s), q_{ij}(s), i \ne j$ are stable and small in some sense, then they can be treated as modeling error terms in the control design. This means that instead of designing an adaptive controller for the MIMO plant (6), we can design *N* adaptive controllers for N SISO plant models of the form

$$y_i = h_{ii}(s).u_i, i = 1, 2, ..., N \quad (7)$$

If these adaptive controllers are designed based on robustness considerations, then the effect of the small un-modeled interconnections present in the MIMO plant will not destroy stability. This approach, known as **decentralized adaptive control**. The analysis of decentralized adaptive control designed for the plant model (7) but applied to (6) follows directly from that of adaptive control for plants with un-modeled dynamics.

Therefore decentralizedcontrollers, designed independently for local subsystems and using local available signals for feedback. The design of the local controllers is similar as in scalar case **[14].**

III. Model description [1, 2]

A block diagram of a two area interconnected system for the uncontrolled case is given in appendix .

The state space model for the system is

$\dot{x} = Ax + Bu + Fw$ (8)

$y = Cx$ (9)

where A is the system matrix , B is the input distribution matrix , F is the disturbance matrix , x is state vector, u is the control vector and w is disturbance vector of load changes.

$\dot{X} = \left(\Delta f_1, \Delta P_{T1}, \Delta X_{g1}, \Delta f_2, \Delta P_{T2}, \Delta X_{g2}, \Delta P_{tie}, \Delta P_{C1}, \Delta P_{C2}\right)^T$ $u = \left[\Delta P_{C1} \quad \Delta P_{C2}\right]^T$ $w = \left[\Delta P_{D1} \quad \Delta P_{D2}\right]^T$, $y = \left[ACE_1 \quad ACE_2\right]^T$

where the matrices A,B and F are defined in appendix . The matrices A,B, and C are time invariant, of compatible dimensions and the matrices A,B,C are assumed to have unknown constant entries which takes values in bounded range. It is also assumed that within the bounded range the triplets (A, B, C) for all areas are controllable, output stabilizable and observable.

The basic structure of the MRAC scheme for individual areas is shown in figure 1.

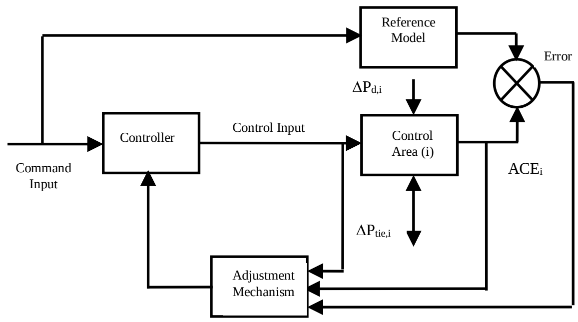

Figure 1: MRAC scheme for i_{th} area

IV.Choice of Reference Model

In the design of MRAC the reference model is chosen as per assumption made in the design of MRAC [14].For the load frequency control the following transfer function is chosen as the reference model. All the desired specifications have been incorporated in the model output. The specifications are explicit from the response shown in figure 2.

$$W_m(s) = \frac{-500s}{s^4 + 24.18s^3 + 221.46s^2 + 1174.7s + 3782.25} \quad (10)$$

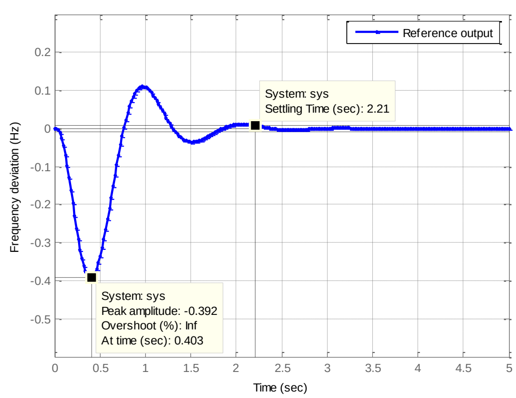

Figure 2. Reference Model output

V.Ziegler-Nichol's Rule based tuning

For the comparison the PID controller was tuned using Ziegler–Nichols tuning rule based on the critical gain K_{cr} and critical period P_{cr}. Values of $K_{cr}$and P_{cr} were calculated from the sustained oscillations of the output by employing only proportional controller [**17**].

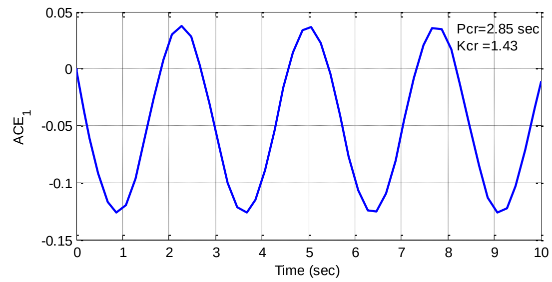

Figure 3. System response with only proportional controller under critical gain

Controller	K_c	T_i	Td
PI	$0.45.K_{cr}$ = 0.6435	$P_{cr}/1.2$ = 2.375	-
PID	$0.6.K_{cr}$ = 0.858	$P_{cr}/2$ = 1.425	$P_{cr}/8$ = 0.3562

VI. Simulation Results

To test the system performance a two area power system has been considered**[17].**The parameters of the power systems are as givenbelow.Simulation results are shown for a step disturbance of 0.1 pu in area-1.Load disturbance is applied at t = 5 sec. The adaptation gain for the MRAC controller is 0.5.

$T_{sg1} = T_{sg2} = 0.4\text{sec}, T_{t1} = T_{t2} = 0.5\text{sec}, T_{ps1} = T_{ps2} = 20\text{sec}, K_{ps1} = K_{ps2} = 100, R_1 = R_2 = 3, b_1 = b_2 = 0.425,$
$2\pi T_{12} = 0.05, a_{12} = 1$

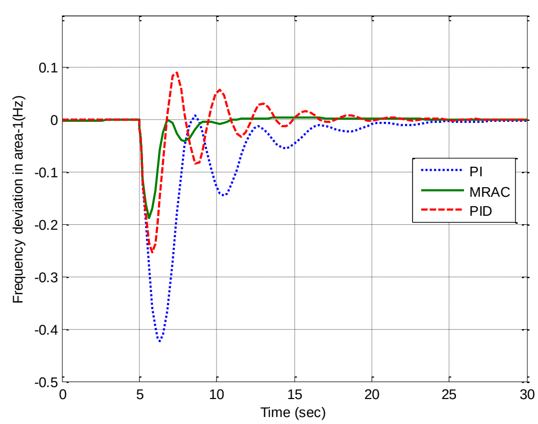

Figure 4. Frequency deviationsat area-1

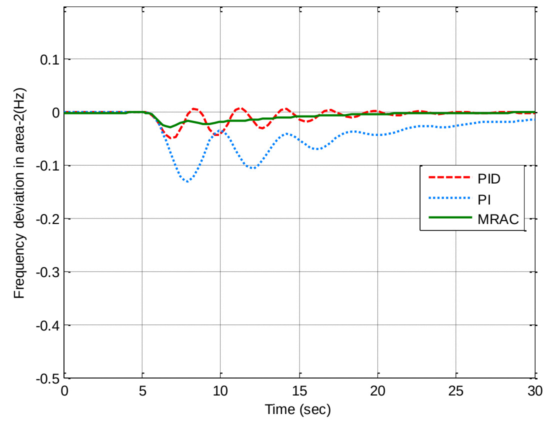

Figure 5. Frequency deviationsat area-2

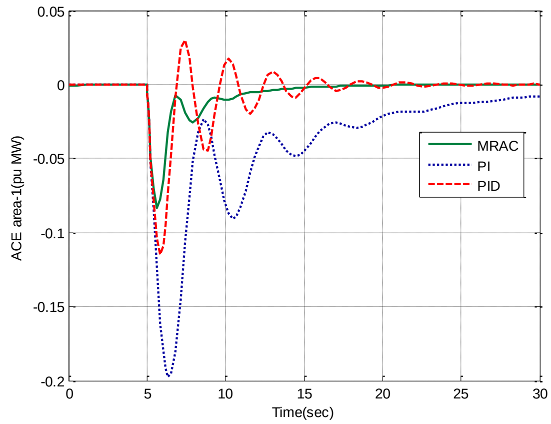

Figure 6. Area Control Error atarea-1

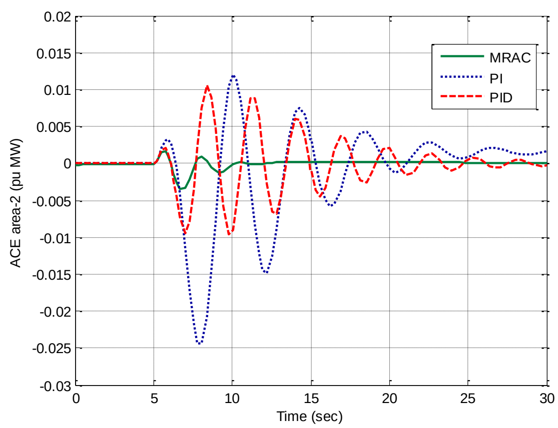

Figure 7.Area Control Error at area-2

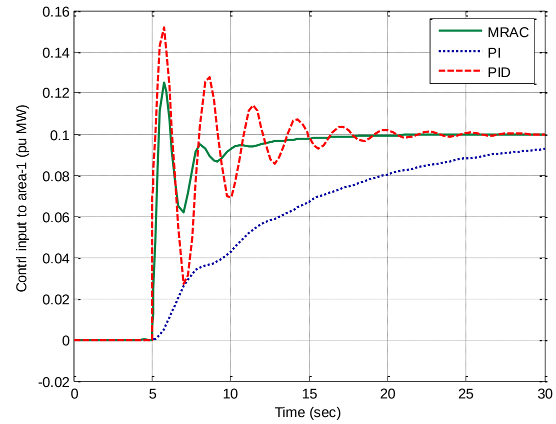

Figure 8. Control input area-1

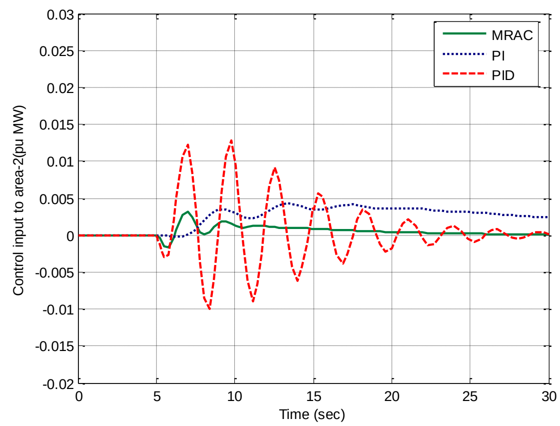

Figure 9. Control input at area-2

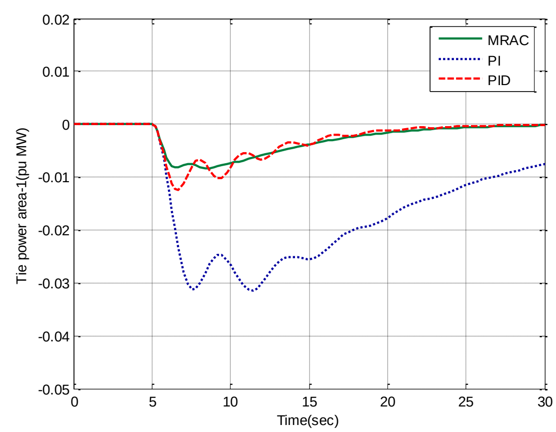

Figure 10. Tie power (inflow) in area-1

VIII. Conclusions

Figures 4-10 show the time domain performance of LFC system withPI,PID and MRAC controller. System is simulated for 30 seconds with step disturbance of 0.1 pu in load of area 1.Disturbance was given at t=5sec.As seen from the plots that MRAC adaptive controller gives better performance in terms of overshoot and settling time. With MRAC controller oscillations are damped out within the 6seconds without violating the input limit to the control valve. Hence, it can beexplicitly claimed that the results of MRAC are more promising for AGC problem.

Appendix

Matrices A, B and F of section III :

$$\begin{bmatrix} \frac{1}{T_{ps1}} & \frac{k_{ps1}}{T_{ps1}} & 0 & 0 & 0 & 0 & -\frac{k_{ps1}}{T_{ps1}} & 0 & 0 \\ 0 & -\frac{1}{T_{t1}} & \frac{1}{T_{t1}} & 0 & 0 & 0 & 0 & 0 & 0 \\ \frac{1}{R_1.T_{sg1}} & 0 & -\frac{1}{T_{sg1}} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -\frac{1}{T_{ps1}} & \frac{k_{ps2}}{T_{ps2}} & 0 & \frac{a_{12}.k_{ps2}}{T_{ps2}} & 0 & 0 \\ 0 & 0 & 0 & 0 & -\frac{1}{T_{t2}} & \frac{1}{T_{t2}} & 0 & 0 & 0 \\ 0 & 0 & 0 & -\frac{1}{R_2.T_{sg2}} & 0 & -\frac{1}{T_{sg2}} & 0 & 0 & 0 \\ 2.\pi.T_{12} & 0 & 0 & -2.\pi.T_{12} & 0 & 0 & 0 & 0 & 0 \\ b_1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & b_2 & 0 & 0 & -a_{12} & 0 & 0 \end{bmatrix}$$

$$B^T = \begin{bmatrix} 0 & 0 & \frac{1}{T_{sg1}} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{1}{T_{sg2}} & 0 & 0 & 0 \end{bmatrix}$$

$$F^T = \begin{bmatrix} -\frac{k_{ps1}}{T_{ps1}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -\frac{k_{ps2}}{T_{ps2}} & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Block diagram of two area system :

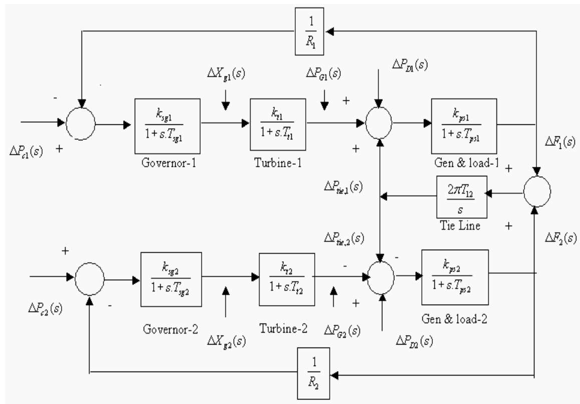

Figure 15. Block diagram of two area power system

References

[1] Elgerd O.I., "Electric Energy Systems Theory: An Introduction "McGraw-Hill, TMH Edition, I Edition, 1982

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

[3] Petras A. Ioannou, "Decentralized Adaptive Control of Interconnected systems" IEEE Transactions on Automatic Control, Vol.AC-31, No.4, April 1986.

[4] 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.

[5] Gavel D.T. and D.D.Siljak, "Decentralised Adaptive Control : Structural Conditions for Stability", IEEE Trans. Auto. Control,Ac-34,413-426,1989.

[6] Ghandakly and Idowu P. "Design of a model reference adaptive stabilizer for the exciter and governor loops of power generators", IEEE Transactions on power systems, Vol.5, No.3, August 1990.

[7] Kautsumi Yamashita & Miyagi Hayagi, "Multivariable self-tuning regulator for load frequency control system with interaction of voltage on load demand"IEE Proceedings-D,Vol. 138,No. 2,March 1991.

[8] 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.

[9] Raymod R.Shoults, "Multi-area adaptive LFC developed for comprehensive AGC simulator"IEEE Transactions on Power systems, Vol.8, No. 2, May 1993.

[10] Rubaai A. and Udo V., "Self-tuning load frequency control: Multilevel adaptive approach" IEE Proceedings on Gen. Transm. Distrib, Vol.141, No. 4, July 1994.

[11] Jiang H. "Global robust adaptive control of power systems",IEE Proceedings on Generation,Distribution,Vol.141.,No.5,September 1994.

[12] Wen Changyun, "Direct Decentralized Adaptive Control of Interconnected Systems Having Arbitrary Subsystem Relative Degrees "Proceedings of the 33rd Conference on Decision and Control, Lake Buena Vista,FL-December 1994.

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

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

[15] Jawad Talaq & Fadel Al-Basri, "Adaptive Fuzzy Gain Scheduling for Load Frequency Control" IEEE Transactions on Power Systems, Vol.14, No.1, February 1999.

[16] Nagrath I.J.and Kothari D.P., "Power System Engineering"Tata McGraw Hill Publishing Company Ltd. New Delhi,2000

[17] Zribi M.,Al-Rashed and Alrifai M., "Adaptive decentralized load frequency control of multiarea power systems"Electrical Power and Energy Systems ,Elsevier ,27(2005) 575-583.

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

[19] 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.

[20] Prabhakar R. Pagilla, Member, IEEE, Ramamurthy V. Dwivedula, Member, IEEE and Nitesh B. Siraskar " A Decentralised Model Reference Adaptive Controller for Large Scale Systems" IEEE/ASME Transactions on Mechatronics, Vol. 12, No. 2, April 2007.

[21] 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.

[22] A.V.Ravi Teja, Member IEEE, Chandan Chakraborty, Senior Member IEEE, Suman Maiti and Yoichi, Fellow IEEE, " A New Model Reference Adaptive Controller for Four Quadrant Vector Controlled Induction Motor Drives" IEEE Transactions on Industrial Electronics, Vol. 59, No. 10, October, 2012.

[23] Adamu Abdullahi, Sirin Akkaya, " Adaptive Cruise Control : A Model Reference Adaptive Control Approach Approach" 2020 24th International Conference on System Theory and Computing (ICSTCC).

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