controller. The P (proportional) gain, is then increased (from zero) until it reaches the ultimate gain , at which the output of the control loop oscillates with a constant amplitude and the oscillation period are used to set the P, I, and D gains. The bode plot is plotted for the open loop transfer function.

The critical frequency obtained (ω_c) is 3.46 rad/sec, magnitude of the open loop transfer function is 0.0186

Ultimate gain, $K_U = \frac{1}{|G(s)|} = 92.047$

Oscillation period, $P_U = \frac{2\pi}{\omega_c} = 1.8159$

The parameters of PID controller,

$K_P = \frac{K_U}{1.7} = 54.145$

$T_I = \frac{P_U}{2} = 0.9079$

$T_D = \frac{P_U}{8} = 0.2269875$

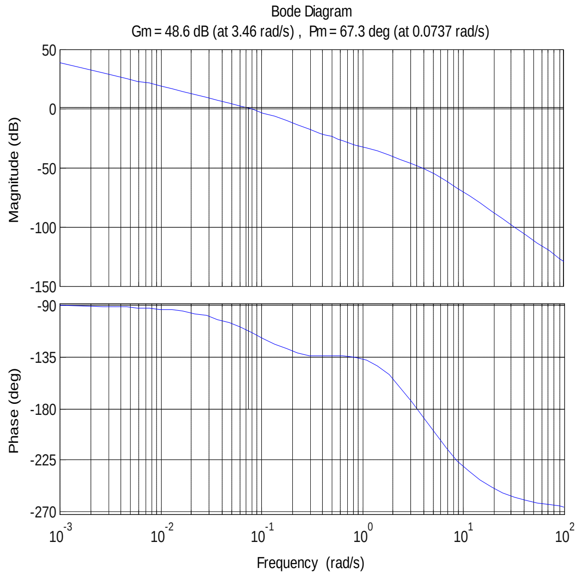

Figure 3: Bode plot of steam turbine system

Transfer function of PID controller

$$PID(s) = K_P\left(1 + \frac{1}{T_I s} + T_D s\right)$$

$$= 54.145\left(1 + \frac{1}{0.9079\ s} + 0.227\ s\right) \quad (13)$$

5. Model Reference Adaptive Control

The Model Reference Adaptive Systems(MRAS) derived for deterministic continuous-time signals is an important adaptive control where desired performance expressed in terms of reference model thus responding to the command signal, other than the normal feedback loop there is another to change the controller parameters with respect to the error. The parameter adjustment mechanism can be gradient method or by using stability theory[2].

The MIT(Massachusetts institute of technology) rule central to the adaptive nature of the controller aims to minimize the squared model cost function by which the error function minimized for perfect tracking between actual plant output (y) and reference model output (y_m).

Tracking error,

$$e(t) = y_p(t) - y_m(t) \quad (14)$$

One possibility to adjust parameters in a way that loss function

$$J(\theta) = \frac{e^2(\theta)}{2} \quad (15)$$

To make J small, negative gradient make the update rule,

$$\frac{d\theta}{dt} = -\gamma\frac{\partial J}{\partial \theta} = -\gamma e\frac{\partial e}{\partial \theta} \quad (16)$$

θ = controller parameter vector
γ= Adaptive gain

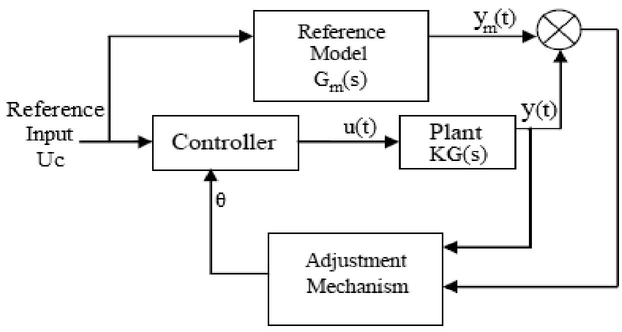

Figure 4: Basic block diagram of a MRAC system

If the process is linear with transfer function $KG(s)$ and K is unknown. The underlying design gives a system with transfer function $K_0G(s)$, where K_0 is a known parameter.

$$E(s) = KG(s)U(s) - KoG(s)Uc(s) \quad (17)$$

Defining a control law,

$$u = \theta u_c \quad (18)$$

$$\frac{\partial e}{\partial \theta} = KG(s)U_c(s) = \frac{K}{K_0}Y_m(s) \quad (19)$$

$$\frac{d\theta}{dt} = -\gamma e\frac{K}{K_0}y_m = -\acute{\gamma} e y_m \quad (20)$$

5.1 Design of PID Controller using MIT rule

When the parameter of any systems changes with respect to time then the conventional controller action is not effective. In case of MRAC based design the adjustable parameters corresponding to changes in plant will be determined by referring to reference model specifying the property of desired control system. For designing purpose the reduced order model of our plant is

$$G(s) = \frac{0.01323s + 0.01187}{s^2 + 0.1424s - 8.003e^{-17}} \quad (21)$$

And the reference model chosen here is

$$G_M(s) = \frac{64}{s^2 + 16s + 64} \quad (22)$$

The characteristics or system parameters are usually not always the same. For these reasons, tuning of the traditional PID controller parameters to control this system for the

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required performance faces a strong challenge, so it is better to adapt the tuning parameters by an adaptation rule.

PID Controller output,

$$U = K_p(1 + \frac{1}{T_i s} + T_d s)(U_c(s) - Y(s)) \quad (23)$$

Plant output,

$$Y(s) = \frac{(\alpha_1 s+\alpha_2)\theta_1 U_c}{\alpha_3 s^2+\alpha_4 - \alpha_5 + (\alpha_1 s+\alpha_2)(\theta_2+\theta_3 s+\frac{\theta_5}{s})} \quad (24)$$

Error = $Y(s) - Y_m(s)$

$$\frac{\partial e}{\partial \theta_1} = \frac{(\alpha_1 s+\alpha_2)\,U_c}{\alpha_3 s^2+\alpha_4 s-\alpha_5+(\alpha_1 s+\alpha_2)(\theta_2+\theta_3 s+\frac{\theta_5}{s})} \quad (25)$$

$$\frac{\partial e}{\partial \theta_2} = \frac{(\alpha_1 s+\alpha_2)\,\frac{U_c}{s}}{\alpha_3 s^2+\alpha_4 s-\alpha_5+(\alpha_1 s+\alpha_2)(\theta_2+\theta_3 s+\frac{\theta_5}{s})} \quad (26)$$

$$\frac{\partial e}{\partial \theta_3} = \frac{-(\alpha_1 s+\alpha_2)\,y}{\alpha_3 s^2+\alpha_4 s-\alpha_5+(\alpha_1 s+\alpha_2)(\theta_2+\theta_3 s+\frac{\theta_5}{s})} \quad (27)$$

$$\frac{\partial e}{\partial \theta_4} = \frac{-(\alpha_1 s+\alpha_2)\,sy}{\alpha_3 s^2+\alpha_4 s-\alpha_5+(\alpha_1 s+\alpha_2)(\theta_2+\theta_3 s+\frac{\theta_5}{s})} \quad (28)$$

$$\frac{\partial e}{\partial \theta_5} = \frac{(\alpha_1 s+\alpha_2)\,\frac{y}{s}}{\alpha_3 s^2+\alpha_4 s-\alpha_5+(\alpha_1 s+\alpha_2)(\theta_2+\theta_3 s+\frac{\theta_5}{s})} \quad (29)$$

Approximating with reference model

$$\frac{(\alpha_1 s+\alpha_2)}{\alpha_3 s^2+\alpha_4 s-\alpha_5+(\alpha_1 s+\alpha_2)(\theta_2+\theta_3 s+\frac{\theta_5}{s})} = \frac{16s+64}{s^2+16s+64}$$

5.2 Design of PID Controller With Lyapunov Rule

The adjustment rule obtained by Lyapunov rule is simpler. The proportional, integral and derivative parameters in control law are adapted using the adjustment mechanism.

Controller output,

$$U = K_p(1 + \frac{1}{T_i s} + T_d s)(U_c(s) - Y(s)) \quad (30)$$

Let plant transfer function is

$$G(s) = \left(\frac{\alpha_1 s+\alpha_2}{\alpha_3 s^2+\alpha_4 s-\alpha_5}\right) = \frac{Y(s)}{U(s)} \quad (31)$$

$$\ddot{y} = \frac{1}{\alpha_3}(\alpha_1\dot{u}+\alpha_2 u-\alpha_4\dot{y}-\alpha_5 y) \quad (32)$$

Let model transfer function,

$$G_M(s) = \frac{64}{s^2+16s+64} = \frac{Ym(s)}{Uc(s)} \quad (33)$$

$$\ddot{y} = 64U_c - 16y' + 64y \quad (34)$$

Error = $Y(s) - Y_m(s)$

From the Lyapunov function, V(e, θ_1, θ_2, θ_3, θ_4, θ_5)

Therefore,

$$\frac{d\theta_1}{dt} = -\gamma u_c e \quad (35)$$

$$\frac{d\theta_2}{dt} = -\gamma \frac{u_c}{s} e \quad (36)$$

$$\frac{d\theta_3}{dt} = \gamma y e \quad (37)$$

$$\frac{d\theta_4}{dt} = \gamma \dot{y} e \quad (38)$$

$$\frac{d\theta_5}{dt} = -\gamma \frac{y}{s} e \quad (39)$$

Thus integrating these values we obtain adapted parameter values which can direct plant output o desired output.

6. Simulation Results

The simulation results were presented to illustrate the performance, and to compare the proposed strategy with the existing PID controller. Figures 8 provide the responses of the PID controller under disturbances in load for different operating conditions. Test results demonstrated the feasibility and effectiveness of proposed approach. Its performance comparison proved its superior disturbance rejection response to variations in load and reference pressure. The convergence rate depends directly on the value of adaptation gain, γ. Simulation results indicate it is true for small values of γ but behavior is quite unpredictable for large values and so the selection of γ is crucial.

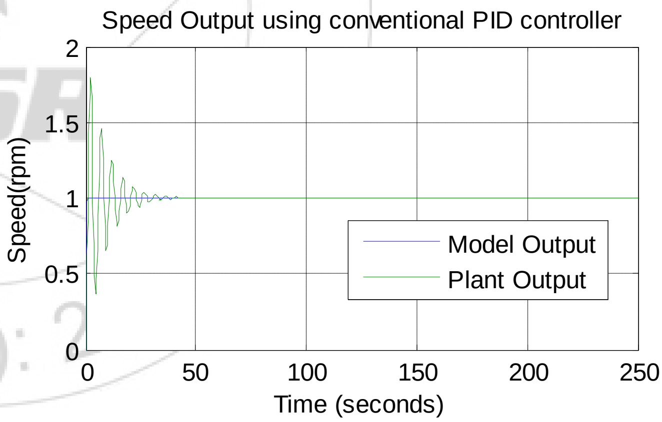

Figure 5: Speed Control using Conventional PID controller

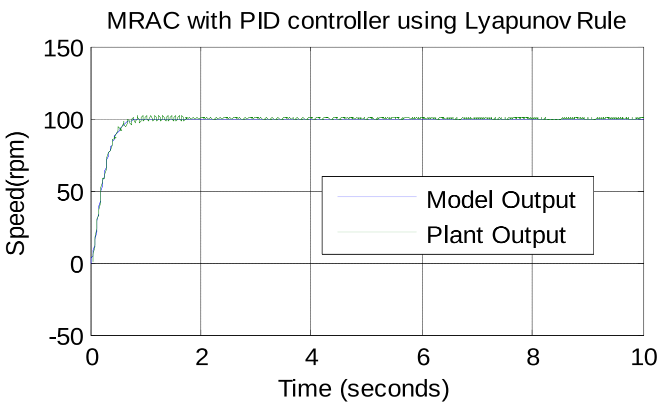

Figure 6: Speed control using MRAC Lyapunov rule with PID controller

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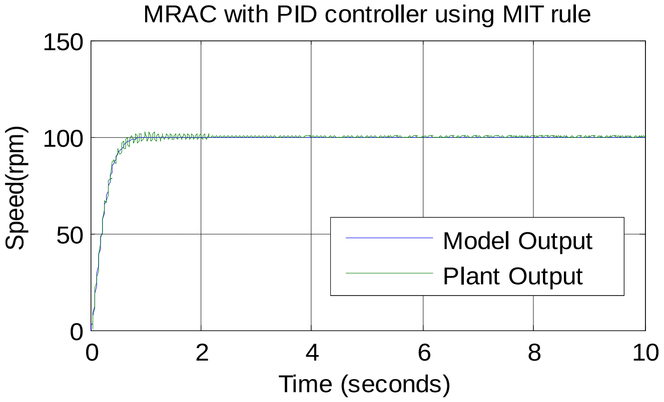

Figure 7: Speed control using MRAC MIT rule with PID controller

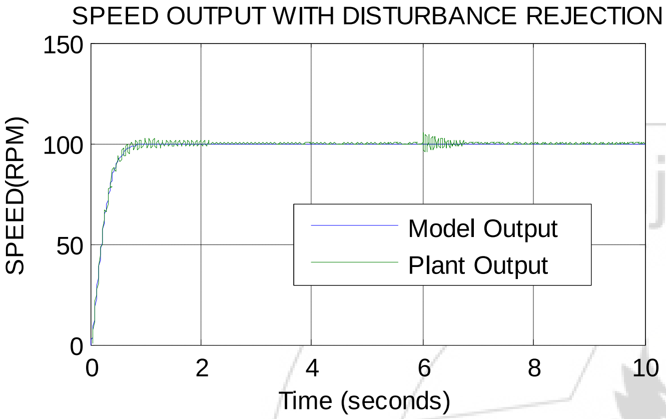

Figure 8: Speed control using MRAC with PID controller

Table 2: Performance comparison using different controllers

Adaptation mechanism	*Controller*	*Peak Overshoot*	*Settling time(sec)*
Zeigler-Nichols tuning	PID	180	40
MIT rule	PID	103	4
Lyapunov rule	PID	102	4.5

7. Conclusion

It is obvious that the MRAC controller,applied to more complicated problems which is designed based on the main system, does not impose any overshoot to the system for an increase in reference pressure as the design requires approximations to obtain sensitivity derivatives. The convergence driving error to zero increases with increasing gain. The turbine speed is achieved by coordinate control of steam pressure with improved precision, reduced steady state error and fast response.

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Author Profile

Sherin A Kochummen was born in Kerala, India in 26/10/1991. She received B.Tech degree in Electrical and Electronics Engineering from Baselios Mathews II College of Engineering, Kollam, India in 2013.Currently, she is pursuing her M Tech degree in Industrial Instrumentation & Control from TKM College of Engineering, Kollam, India. Her research interests include Control Systems. (sherinakoc@gmail.com)

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