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Model Reference Adaptive Control for Agriculture Application

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Abstract- A new approach to adaptive model reference control, based on MIT rule is presented. Modern agricultural machines happen to work for prolonged periods of time in considerably harsh environments. This puts a higher demand on the automatic control systems and steering control in particular. Long-term machine operation leads to variance of the physical parameters of the working fluid, positive overlap in proportional valve, working temperature and machine components. In this paper we will be discussing about Model Reference Adaptive control (MRAC) which is an approach to solve real world problems related to Adaptive Control. The present research is focused on the design and application of model reference adaptive controller (MRAC) for control of steering angle of a heavy duty agriculture mobile machine through a hydraulic cylinder. The synthesized controller is based on simple integrator model of the steering cylinder and Lyapunov stability theorems. The closed-loop system achieves good performance and the adaptive gain is stabilized around its mean value too.

Keywords: *Model Reference Adaptive control (MRAC), Steering, Agricultural, MIT Rule*

1. Introduction

Since the model reference adaptive control (MRAC) strategy was proposed, it has been widely used in various practical control systems due to its adaptive ability to changing con-trolled objects and the stability guaranteed by the design process based on the Lyapunov function [1]-[6]. In partic-ular, MIT control strategy with the simplest form [7], [8] and MRAC strategy based on input and output variables [9] are widely used. In more and more practical applications, researchers and users are aware of the benets of applying MRAC strategy, but also more clearly aware of its shortcomings. In this paper we will be discussing about Model Reference Adaptive control (MRAC) which is an approach to solve real world problems related to Adaptive Control. MRAC is used for making a closed loop controller which adjusts the variables of the system dynamically by comparing the output of the plant with a standard reference response [2]. Their applications span across sectors such as manufacturing, the electrical industry, process automation, and the automotive industry, among others [1, 2]. These systems integrate components like pulleys, belts, shafts, and mechanical couplings, all of which contribute to their functional versatility. However, induction motors (IMs) and gearboxes (GBs) are the most prominent components in industrial electromechanical systems due to their unique ability to convert electrical energy into mechanical energy while managing torque transmission efficiently [3]. The main purpose when development an adaptive control algorithm is to find an effective approach for tuning the embedded controller parameters according to plant dynamics variations, which is due to disturbances and/or unmodelled dynamics and changes in mode of operation [11]. The effectiveness of the adaptive control scenario can be estimated by enhancements in performance EHSU. For example such improvement can be achieved through reducing the dead-band of the system or enhancing command modulation [12]. In the EHSU, the dead-band depend of the positive overlap of proportional spool valve for control of steering cylinder piston position.

This paper present design and implementation of model reference adaptive control (MRAC) for electrohydraulic power steering system that is applicable in modern agriculture machine. The goal of control algorithm is to overcome a number of limitations in the control of hydraulic systems in mobile machines - variance of the physical parameters of the working fluid, positive overlap in proportional valve, working temperature and other.

2. MIT Rule

The MIT rule is the main approach to solve MRAC. To apply MRAC we need a closed loop system which can be adjusted by the parameter theta. Since we need an adjustment mechanism so that the error between the model and plant becomes zero, a tracking methodology can be evolved.

Let the error of the output(y) related to the closed loop system and output (ym) belonging to the model be:

$$e = y - y_m \tag{1}$$

Let the cost function be

$$J(\theta) = \frac{1}{2}e^2(\theta) \tag{2}$$

which has to be minimized.

Let the process of plant and model be:

$$G(s) = \frac{y}{u} \tag{3}$$

$$G_m(s) = \frac{y_m}{u_c} \tag{4}$$

The control law is represented as:

$$u(t) = f(u_c,\ y) \tag{5}$$

Error:

$$e_0 = y - y_m \tag{6}$$

$$\frac{\partial e}{\partial \theta} = \frac{\partial y}{\partial \theta} \tag{7}$$

$$\frac{d\theta}{dt} = -\gamma e \frac{\partial e}{\partial t} \tag{8}$$

where γ is tuning parameter and $\frac{\partial e}{\partial t}$ is known as sensitivity derivative.

3. Electrohydraulic Steering System: The embedded MRAC controller is intended for a electrohydraulic power steering system which is based on EHSU type OSPEC200 LSRM. The laboratory test rig is design and implemented according to technical data sheet from the mobile machine manufacturers [11]. The hydraulic diagrams of the test rig system is described particularly in [12]. Fig.1 presents principle hydraulic scheme of the digital system for control of steering unit drives by digital valve actuator. The steering operations are done by three main constructive elements – an electrohydraulic control module (type PVE), a pilot operated proportional valve and an executive hydraulic cylinder. When control action u(t) > 0, the left digital switching valve drive the spool of the valve to the right direction. When u(t) < 0 valves in the right are switched by PWM signal to drive the spool to the left direction. The proportional valve determinate a flow rate direction of hydraulic fluid which supplies the both steering cylinder chambers. Steering cylinder controller $K_{YCL}(s)$ measures steering piston position and calculates the control signal u(t) in order to achieve desired reference r(t). The reference signal can be generated by steering wheel, joystick or GPS based system.

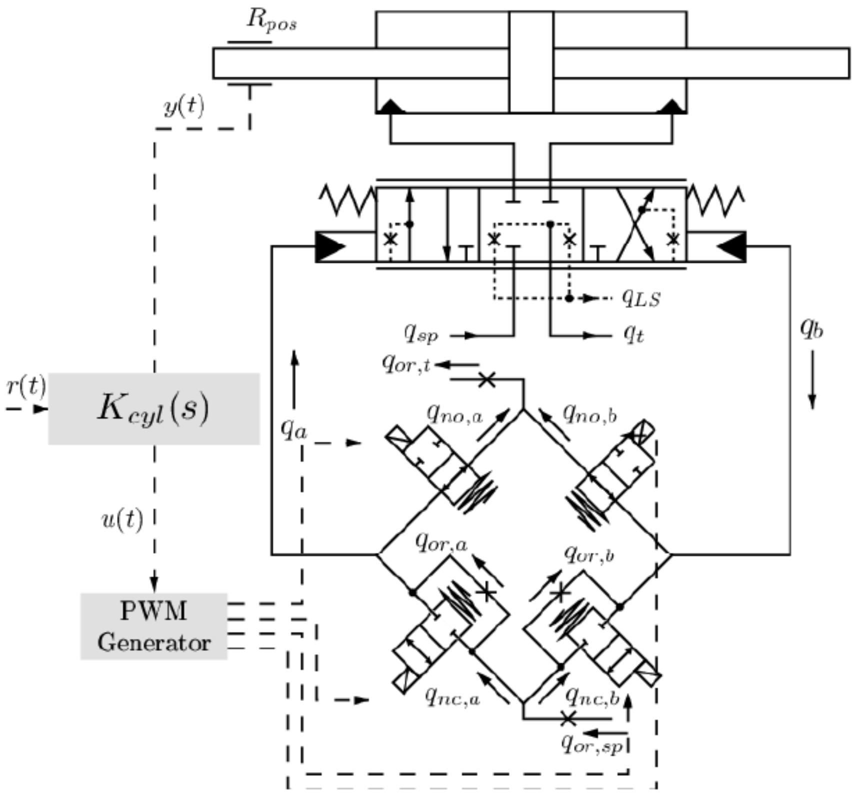

Fig. 1: Digitally controlled power steering system

The main components of embedded control system are joystick JS6000, microcontroller MC012-022 [11], EHSU OSPEC200LSRM with electrohydraulic convertor PVE module, steering cylinder, linear position sensor (Fig.1). The communication between control system components is done by CAN network. We use PLUS+1 Guide software environment to develop software, to load control algorithm and to process output data. MC012-022 controller being CE compliant is one of the appropriate devices for use in distributed machine control system. The microcontroller architecture is based on Digital Signal Processor (DSP) TMS320F2812 from Texas Instruments (TI) providing 150MHz processing speed, 128K internal flash, multifunction input and 32-bit fixed-point arithmetic. Its output ports can generate PWM signals and input ports can measure voltage, frequency and resistance.

4. Model Reference Adaptive Control Design:

The design of a MRAC controller is done based on development closed-loop system scheme presented in Figure 2.

Let assume that the steering cylinder and the hydraulic systems are modeled by a simple integrator equation as

$$\dot{y}(t) = ku(t) \tag{9}$$

where y(t) is the steering cylinder position, u(t) is the voltage PWM signal applied to the PVE transducer and k is an unknown system gain, possibly slowly varying with time due to physical parameter drift. The proposed controller we select as an adaptive P-based output feedback as

$$u(t) = \theta(t)(r(t) - y(t)) \tag{10}$$

where r(t) is the desired steering angle and $\theta(t)$ is the adaptive gain. The closed loop system then is described by the following expression

$$\dot{y}(t) = k\theta(t)(r(t) - y(t)) \tag{11}$$

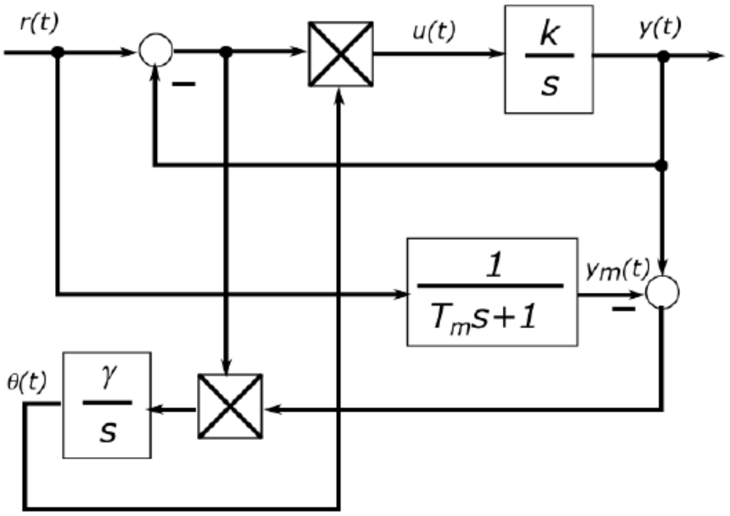

Fig. 2: Closed loop MRAC controller design

The adaptation of the parameter $\theta(t)$ will be according to the output reference model

$$\dot{y}_m(t) = -\frac{1}{T_m} y_m(t) + \frac{1}{T_m} r(t) \tag{12}$$

This represents an aperiodic model with a time-constant T_m and unit gain. So after as much as $5T_m$ the output $y_m(t) \to r(t)$. The goal is to select the parameter $\theta(t)$ such that reference model error $e_m(t) = y(t) - y_m(t)$ to be minimized. In order to investigate the convergence of the $e_m(t)$ we find its first derivative

$$\dot{e}_m(t) = \dot{y}(t) - \dot{y}_m(t) \tag{13}$$

After substituting the corresponding terms with the expressions define above we get

$$\dot{e}_m(t) = k\theta(t)r(t) - k\theta(t)y(t) + \frac{1}{T_m} y_m(t) - \frac{1}{T_m} r(t) \tag{14}$$

After grouping the term according to their places in the control loop the derivative of the model reference error becomes

$$\dot{e}_m(t) = -\frac{1}{T_m} e_m(t) + \left(\frac{1}{T_m} - k\theta(t)\right)(r(t) - y(t)) \tag{15}$$

From this form it is evident that we can select the following Lyapunov function

$$V(e_m(t), \theta(t)) = e_m^2(t) + \left\{\frac{1}{T_m} - k\theta(t)\right\}^2 \tag{16}$$

To achieve stability of the closed-loop according to the

second Lyapunov method the total derivative of the Lyapunov function with respect to time must be non-increasing

$$\frac{dV(e_m(t), \theta(t))}{dt} < 0 \tag{17}$$

Hence by differentiating the expression for V we get

$$\dot{V} = 2e_m\dot{e}_m - 2k\left(\frac{1}{T_m} - k\theta(t)\right)\dot{\theta}(t) \tag{18}$$

Now substituting the expression for the derivative of the model error

$$\dot{V} = 2e_m\left[-\frac{1}{T_m}e_m(t) + \left\{\frac{1}{T_m} - k\theta(t)\right\}\{r(t) - y(t)\}\right] - 2k\left\{\frac{1}{T_m} - k\theta(t)\right\}\dot{\theta}(t) \qquad (19)$$

By grouping the terms the resultant expression becomes

$$\dot{V} = -\frac{2}{T_m}e_m^2(t) + \left[\frac{1}{T_m} - k\theta(t)\right]\left\{2e_m e(t) - 2k\dot{\theta}(t)\right\}, \qquad (20)$$

where $e(t) = r(t) - y(t)$ is the feedback error. Now the sufficient condition for the stability condition $\dot{V}(t) < 0$ to be satisfied is

$$2e_m e(t) - 2k\dot{\theta}(t) = 0 \qquad (21)$$

or

$$\dot{\theta}(t) = \gamma e_m(t)\{r(t) - y(t)\}, \qquad (22)$$

where $\gamma = \frac{1}{k}$ is a tunable parameter.

5. Model Reference Adaptive Control Design:

The controller is developed in a simulink environment and subsequently used for automatic code generation via PLC Coder [4]. The resulting Structured Text (ST) code is deployed on a Danfoss MC012-022 microcontroller to experimentally validate the proposed adaptive algorithm on a dedicated test bench. Figure 3 illustrates the experimentally obtained transient response of the steering cylinder piston in a closed-loop configuration incorporating the embedded MRAC algorithm. The reference input is a periodic pulse signal with a period of 100 seconds. Its amplitude corresponds to a ±0.1 m displacement of the steering cylinder piston relative to the central (zero) position.

The adaptive control scheme is realized in discrete time. The integrator for θ is implemented as a discrete-time integrator with a sampling period of $T_s = 0.025$s. In addition, the aperiodic reference model is approximated by a discrete-time transfer function $W_m(z)$ using the same sampling interval. The desired performance is selected as aperiodic first order system without overshot

$$W_m(z) = \frac{0.01}{z - 0.99} \qquad (23)$$

The cylinder output converges to the reference value after several cycles, during which the feedback gain θ gradually adjusts to its steady-state level. The associated control input is shown in Figure 3. The control signal remains within the allowable limits of ±5 V, while utilizing the entire available control range.

Figure 5 illustrates the evolution of the feedback gain parameter, clearly showing the adaptation process. The adjustable parameter settles to its steady-state value after approximately 400 seconds. Minor oscillations in the parameter are caused by changes in the reference signal; however, their magnitude is small relative to the final steady-state value. Figure 6 depicts the model tracking error employed in the adaptation mechanism.

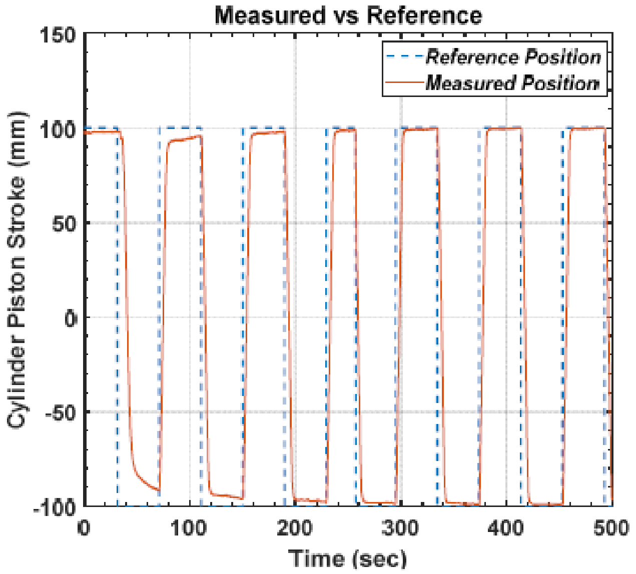

Fig. 3 Measured cylinder piston stroke

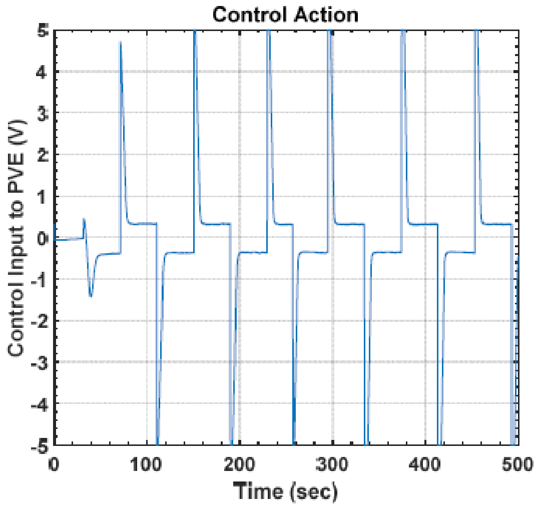

Fig. 4 Measured control signal

Figure 7 presents the experimentally measured spool position of the proportional valve during step-response reference tracking. The signal is acquired via the LVDT feedback sensor integrated into the EHSU. As observed, there is a strong correlation between the dynamic behaviour of the control input and the spool displacement signal. This confirms the proper operation of the hydraulic subsystem in response to the control signal generated by the implemented MRAC algorithm.

Figure 8 shows the experimentally recorded flow rate through the EHSU supplying the cylinder chambers during reference tracking. In the steering test rig, the flow is provided from the priority valve to the EHSU. This measurement also serves as an indicator for evaluating the system's energy efficiency [5], since the flow rate is approximately 12 l/min, compared to the pump capacity of about 30 l/min.

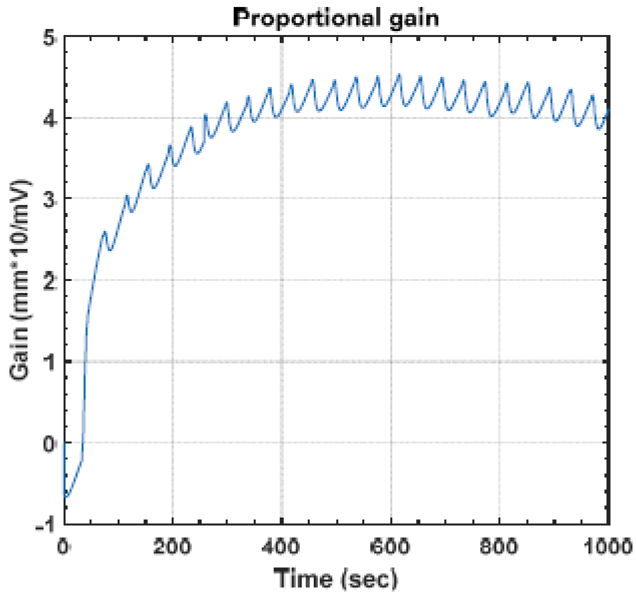

Fig. 5 Proportional gain variation

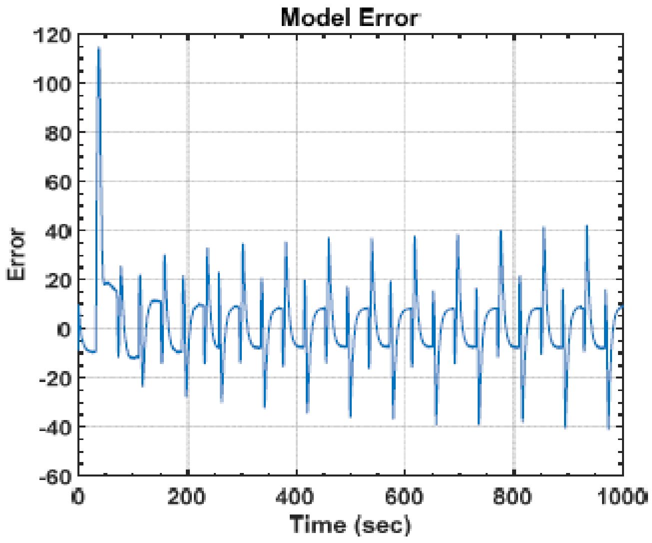

Fig. 6 Proportional gain variation

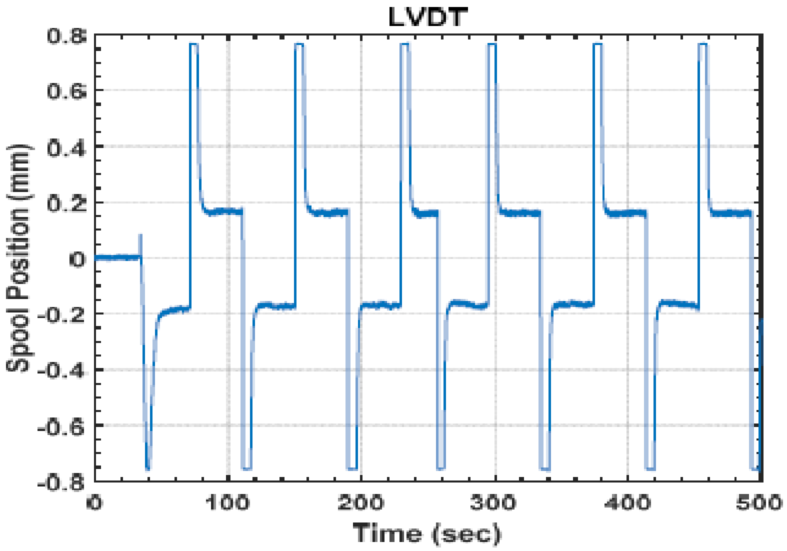

Fig. 7 Measured spool position

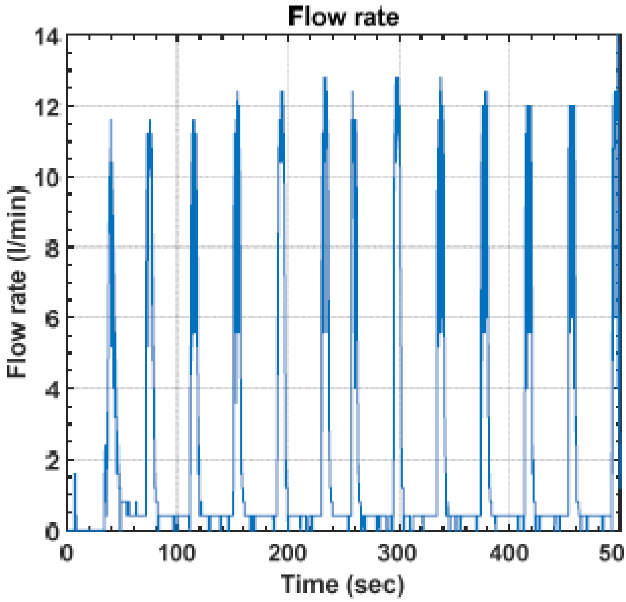

Fig. 8 Measured flow rate

6. Conclusions: The paper describes the development and realization of a Model Reference Adaptive Control (MRAC) strategy for an electrohydraulic power steering system intended for application in agricultural mobile machinery. The key contribution of the proposed embedded controller lies in its ability to compensate for several inherent limitations in hydraulic control systems used in mobile equipment, such as variations in fluid properties, positive overlap in the proportional valve, changes in operating temperature, and other parameter uncertainties. The effectiveness of the approach is validated through experimental investigations conducted on a laboratory test bench.

References:

1. H. Goud and P. Swarnkar, “Signal synthesis model reference adaptive controller with artificial intelligent technique for a control of continuous stirred tank reactor”, Int. J. Chem. React. Eng., vol. 17, no. 2, pp. 1-8, Feb. 2019.

2. R. B. Anderson, J. A. Marshall, and J. A. L ‘Aflitto, “Constrained robust model reference adaptive control of a tilt-rotor quadcopter pulling an unmodeled cart”, IEEE Trans. Aerosp. Electron. Syst., early access, Jul. 10, 2020, doi: 10.1109/TAES.2020.3008575.
3. R. Nair and G. Narayanan, “Stator flux based model reference adaptive observers for sensorless vector control and direct voltage control of doubly-fed induction generator”, IEEE Trans. Ind. Appl., vol. 56, no. 4, pp. 3776-3789, Aug. 2020.
4. C. Y. Wu, J. Li, B. Niu, and X. P. Huang, “Switched concurrent learning adaptive control of switched systems with nonlinear matched uncertainties”, IEEE Access, vol. 8, pp. 33560-33576, Feb. 2020.
5. G. Song and G. Tao, “A partial-state feedback model reference adaptive control scheme”, IEEE Trans. Autom. Control, vol. 65, no. 1, pp. 44-57, Jan. 2020.
6. M. S. Amiri, R. Ramli, and M. F. Ibrahim, “Initialized model reference adaptive control for lower limb exoskeleton”, IEEE Access, vol. 7, pp. 167210-167220, Nov. 2019.
7. M. Kumar and B. Tyagi, “Design of a model reference adaptive controller(MRAC) for DC-DC boost converter for variations in solar outputs using modified MIT rule in an islanded microgrid”, in Proc. IEEE Int. Conf. Power Electron., Smart Grid Renew. Energy (PESGRE), Cochin, India, Jan. 2020, pp. 1-6.
8. E. Mathew, T. Pawar, and B. Jaganatha Pandian, “Control of a coupled CSTR process using MRAC-MIT rule”, in Proc. Innov. Power Adv. Com-put. Technol. (i-PACT), Vellore, India, Mar. 2019, pp. 1-6.
9. K. Narendra and L. Valavani, “Stable adaptive controller design-direct control”, IEEE Trans. Autom. Control, vol. 23, no. 4, pp. 570-583, Aug. 1978.
10. N.T. Nyugen, Model Reference Adaptive Control, Moffen Field, CA: Springer International Publishing, pp.83-106,2018.
11. Yang Y, C. Zhou etc. “Model reference adaptive robust fuzzy control for ship steering autopilot with uncertain nonlinear systems”, Applied Soft Computing, Elsevier, 2003.
12. Danfoss, “OSPE Steering Valve”, Technical Information, 11068682, November, 2016.