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ENERGY SAVING IN ELECTRO-HYDRAULIC SYSTEM USING ADAPTIVE NEURO-FUZZY CONTROLLER

Kwanchai Sinthipsomboon[1, a], Issaree Hunsacharoonroj[1,b], Joseph Khedari[1,c] and Watcharin Po-ngaen[b]

[1]Rattanakosin College for Sustainable Energy and Environment, Rajamangala University of Technology Rattanakosin, Thailand

[2]King Mongkut's University of Technology North Bangkok, Thailand

[a]kwanchai@usefloline.com

Keywords: Energy Saving, Electro-Hydraulic System, Neuro-Fuzzy

Abstract. In industrial machinery units in which handle with high loads, hydraulic actuators are often used to actuate the manipulators. The nonlinear effects of the hydraulic system can be a problem if they disturb the energy efficiency of the hydraulic system. In this study, a designed Adaptive neuro-fuzzy Controller for electro-hydraulic system is developed to reduce the energy consumption. An intelligent neuro-fuzzy controller is employed to optimize the quantitative energy of fluid power flow of hydraulic system by the rotation of the electric motor via an inverter. Results of experiment study are presented showing the potential improvement in term of energy saving and pressure servo performance offered by this method.

Introduction

Hydraulic system has been widely used for manufacturing machines and systems have many advantages over other technologies. The dynamic performance is superior when compared to electrical or electrical-mechanical drive systems in large power drive systems [1]. High performance of hydraulic systems still remains a priority, but systems during working period machine that use cylinder and hydraulic motor as an actuator may have several hydraulically functions, with three or more operating simultaneously, e.g. feeding, clamping bending, grinding, cutting, drilling and pressing are providing power for load, hydraulic power varies depending on load and during increase or decrease speed of cylinder or hydraulic motor. When the actuator is accelerated or decelerated using flow control valves there are much pressure drop in component is converted into heat energy which can have determinately effects on and the surrounding environment and energy loss in the system more than 45% change to heat generated in the system [2]. These results in an increasing of temperature, contamination, vibration, leakage and noise in hydraulic system these are all problems of the hydraulic machines. In recent decades, high performance of hydraulic systems still remains a priority, but systems which are energy efficient have been the focus of much study; The demands for highly efficient hydraulic drives has also increased. If the efficiency of hydraulic drive systems cannot be improved, many traditional applications in which they are found will be converted to other power drive systems. Therefore it is very challenging to find out how to reduce the energy loss and heat generation in a conventional hydraulic system and what is the key for energy saving if a common pump is used to supply flow rate to the circuit, this is primarily due to using a controller for electro-hydraulic system is developed to improve the energy saving performance of the hydraulic system considerations.

A conventional hydraulic system which is driven by a hydraulic pump operating at a constant speed of 1450 rpm is typically used. During idle periods the motor continues to rotate at full speed, perhaps consuming 30-45% of full load amperage [3]. The hydraulic power which is function of flow and pressure varies as the actuator speed rises and falls at acceleration and deceleration period in response to cycle time of machines by controlling the rotating speed of the hydraulic pump and prevent unnecessary loss of motive energy by stopping the pump during idle time. A conventional hydraulic system which controlled by hydraulic or electric system, most of the electro-hydraulic system has low efficiency with high energy loss. Therefore, the many researchersare interested in a development of a compact unit electrohydraulic energy saving system using a typical induction motor with an inverter controller [4-7]. The inverter is characterized by load sensing by using soft intelligent controller and employing a fixed displacement pump. The advantages of this pump type are not expensive and very popular in a conventional hydraulic system which is applied for machine control with closed loop electro-hydraulic control or servo control. Also, in addition to controlling the speed of the electric motor driven pump is used to coordinate work with the PID controller in order to reduce losses in the system.

Power Unit in Hydraulic System

In this section,hydraulic power unit systemwill be introduced. The following simple equation was used to describe a behavior of thehydraulicsystem.The output flow of hydraulic oil can be expressed as:

$$Q_p = \frac{\omega \cdot V_{th}}{2\pi} \cdot \eta_{vol} \qquad \text{Eq.1}$$

where Q_p is the pump output flow in m^3/s, ω is the rotation angular speed, $V_{th}$is the theoretical volumetric displacement of the pump in m^3/rev, and η_{vol} is its volumetric efficiency.The differential equation for the pump shaft is

$$J_p \frac{d}{dt}\omega + T_{f,p}(\omega) = T_{motor} - \eta_{vol} T_{p,th} \qquad \text{Eq.2}$$

where the total equivalent inertia of the pump is J_p, $d\omega/dt$ is the pump angular acceleration, T_{motor} is the drive torque, $T_{p,th}$is the theoretical torque required for compressing fluid, $T_{f,p}$is the frictional torque, and the volumetric efficiency of the pump is η_{vol}The theoretical torque to compress the fluid can be modeled as follows

$$T_{p,th} = V_{th}(p_s - p_m) \qquad \text{Eq.3}$$

where the theoretical volumetric displacement for the pump is V_{th}, p_s is the system pressure, and p_m is the tank pressure in Pa.The frictional torque can be modeled as follows

$$T_{f,p}(\omega) = T_v \omega + \text{sign}(\omega) \cdot \left[T_{co} + T_{so} \cdot e^{\left(\frac{-|\omega|}{C_s}\right)} \right] \qquad \text{Eq.4}$$

where T_v is the viscous friction, T_{co} is the Coulomb friction, T_{so} is the static friction, and C_s is the Stribeck friction.For an induction motor, rotor speed, frequency of the voltage source, number of poles and slip are interrelated according to the following equation:

$$n = \frac{120 f_1}{P} \cdot (1 - s) \qquad \text{Eq. 5}$$

where n is mechanical speed (rpm), f_1 is fundamental frequency of the input voltage (Hz), P is number of poles, and s is slip. The utilization of static frequency inverters comprehends currently the most efficient method to control the speed of induction motors. Inverters transform a constant frequency-constant amplitude voltage into a variable (controllable) frequency-variable (controllable) amplitude voltage. The variation of the power frequency supplied to the motor leads to the variation of the rotating field speed, which modifies the mechanical speed of the machine.The torque developed by the induction motor follows the equation below

$$T = k_1 \cdot \phi_m \cdot I_2 \quad \text{Eq. 6}$$

Despising the voltage drop caused by the stator impedance, the magnetizing flux is found to be

$$\phi_m = k_2 \cdot \frac{V_1}{f_1} \quad \text{Eq.7}$$

where T is torque available on the shaft (N.m), ϕ_m is magnetizing flux (Wb), I_2 is rotor current (A) depends on load, V_1 is stator voltage (V), and k_1&k_2 are constants depend on material and on the machine design.For the electro-hydraulic system is designed to mimic the function of a compression machine. Fig 1 illustrates the energy saving test rig in hydraulic system using in this research. The gear pumpis coupling by induction motors and rotation angular speed is controlled by power electronically inverter.ThePressure sensors are mounted strategically on the double acting cylinder to feedback to control system.

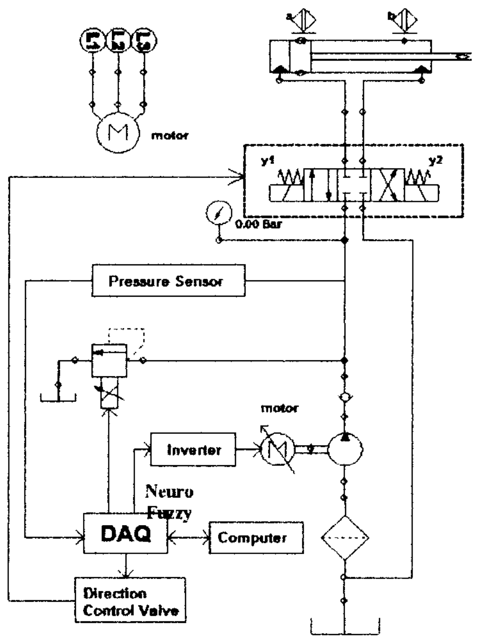

Figure 1 Concept of using a hybrid Fuzzy Controller and PID Controller control hydraulic system

The computer acts as a control unit in order to obtain the load energy for processing andthen transmitting out control signals via DAQ card. For the output signal, digital signal is used to control valve 4/3 (closed-center position) for move in and out of the cylinderand analog control signal is used to adjust oil flow by varying the speed of the electric.

Neuro-Fuzzy Control

Neuro-fuzzy controllers have been expressed in many forms.A frequent representation is a multilayer feed-forward network [8-10]. There has also been some interest in a self–organizing feature map, or unsupervised network as a hybrid system [11,12]. In neural network representation, it can be easy to visualize and analyze the signal flow though the fuzzy network system. Jang [8] introduced the neuro-fuzzy "adaptive network–based fuzzy inference system" in which the Sugeno fuzzy model was represented as a feed-forward neural network. Based on the Jang fuzzy inference model, a simple fuzzy system prototype cooperated with back propagation adopted in this electro-hydraulic system research. The hybrid learning algorithm is employed to adjust two paths of adaptive parameters: the forward path and the backward path. In the forward path, a set $\{p_i, q_i, r_i\}$ is updated by a least mean square estimator. In the backward path, the back-propagation algorithm is performed on the output node and the resulting errors are propagated back to the first node to update the shape of membership functions. It has two inputs (error and rate error), three input membership functions (Gaussian-shape), and one output with a first order linear function.

If **pressure error** is**very large** and **rate pressure** is **large**

Then **velocityof pumpis** p_1.(**pressure error**)+ q_1 (**rate pressure error**) + r_1

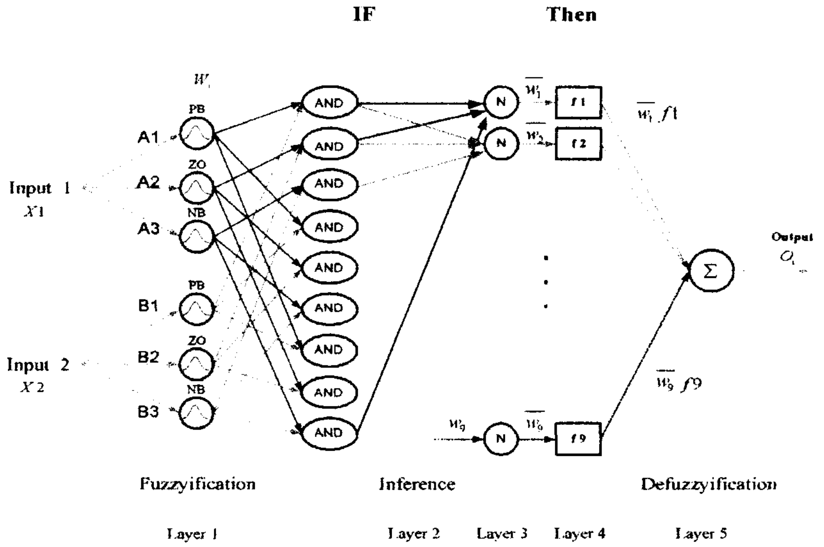

Figure 2. The prototype neuro-fuzzy architecture

On the 1st layer, every node in the input layer, which is a membership function, is an adaptive node. The output of this node is a matching degree of an input to the corresponding membership functions in the fuzzy set.

$$O_{1,i} = \mu_{A_i}(x), \text{ for } i = 1, 2, \text{ and } 3 \qquad \text{Eq.8}$$

$$O_{1,i} = \mu_{B_i}(x), \text{ for } i = 4, 5, \text{ and } 6 \qquad \text{Eq. 8}$$

where $O_{1,i}$ is the fuzzy membership grade of a fuzzy set A (pressure error) and B (rate pressure error).

On the 2nd layer, each node presents an "AND" operator, and is a fixed node whose output is the product of the entire incoming signal.

$$O_{2,i} = w_i = \mu_{A_i}(x).\mu_{B_i}(x), \quad i = 1,2...9 \qquad \text{Eq.8}$$

The 3rd layer is also a fixed node. Each node is calculated by weight averaging.

$$O_{3,i} = \overline{w}_i = \frac{w_i}{w_1 + w_2 + ...w_9} \quad i = 1,2...9 \qquad \text{Eq.9}$$

The 4th layer is an adaptive node with each node calculated by the equation 3.7,

$$\overline{w}_i.f_i = \overline{w}_i(p_i x + q_i y + r_i) \qquad \text{Eq.10}$$

where $\{p_i, q_i, r_i\}$ is a consequent parameter and x, y are the error and the derivative of error inputs respectively.

The 5th layer is a fixed node and represents the summation of all outputs of the 4th layer.

$$\text{Crisp number output} = O_{5,1} = \sum_i \overline{w}_i f_i = \frac{\sum_i w_i f_i}{\sum_i w_i} \qquad \text{Eq.11}$$

There are two sets of parameters for this hybrid neuro-fuzzy system. The first is a first order linear function in the 4th layer, the other is a membership function on the 1st layer.

Experiment SetupExperimental Results

Equipment used in this experiment is to mimic the function of the operation of the compression machine. The main equipment used in such experiments is shown in fig3 and Table 2 respectively.

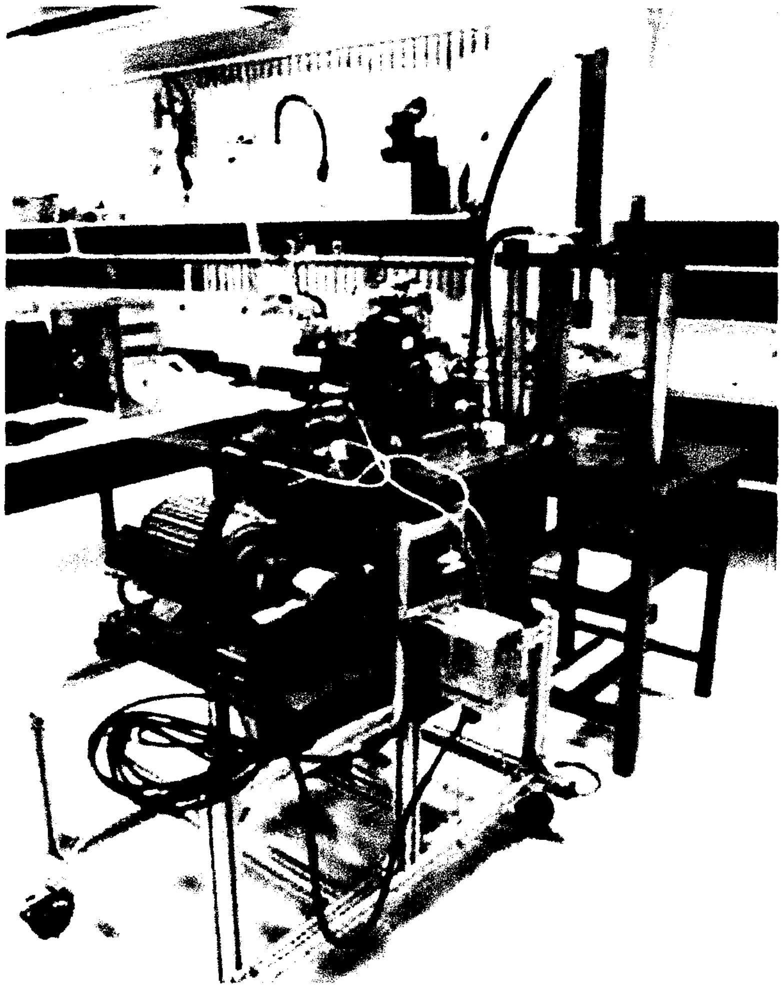

Figure 3 Equipment used in experiment

Table 2. Power consumption of electric motor

Components	Descriptions
Hydraulic pump	Gear pump, 14cc/rev
Induction motor	380V, 50Hz, 3.7kW
Double acting cylinder	Bore size 50mm, Stroke 500mm
Directional control valve	4/3 Solenoid Valve, Double coil , closed center
Pressure relief vale	Control pressure 0-100bars
Proportional pressure relief valve	Voltage input 0-10volts, Control pressure output 0-100bars
Pressure sensor	Input pressure 0-100bars, Output 0-10volts
Proximity sensor	Inductive sensor (on/off)
Inverter	V/F 0-50Hz, 380V, 3.7kW
Current sensor	0-20Amps

In design the electro-hydraulic system for use in experiments to simulate the operation of the compression machine, the sequence procedure is illustrated in the fig4.The DAQ card cooperation with graphical programming is using tocontrol and obtain the power consumption data from the experimental test rig.To evaluate any improvement in the hydraulic compression system, corresponding comparative control experiments were conducted by moving the cylinder press contract with the obstacle. The pressure of the operation was set at a 100 Bar.

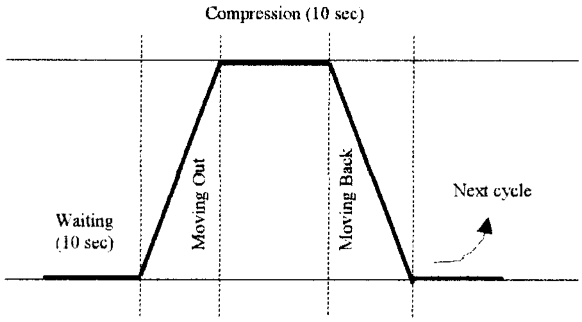

Figure 4. The cycle time of the compression machine

The dynamic response of pressure and current consummtion was investigated. For the comparative pressure response results, fig.5 illustrateusing a PID, fuzzy, and adaptive neuro-fuzzycontroller. for the overall tracking of the pressure control, whilst the PID control scheme presents the not satisfied pressure servo performance,a very large rise time. However, this problem was overcome with the intelligent fuzzy and neuro-fuzzy controllerand could achieve satisfactory for robust control.

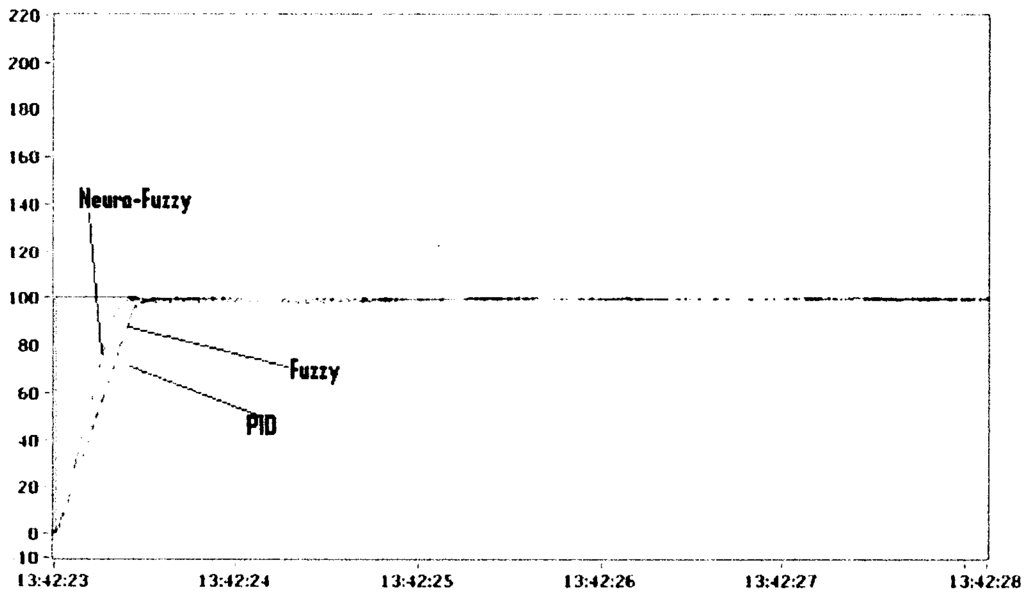

Figure 5 Pressure control dynamic response

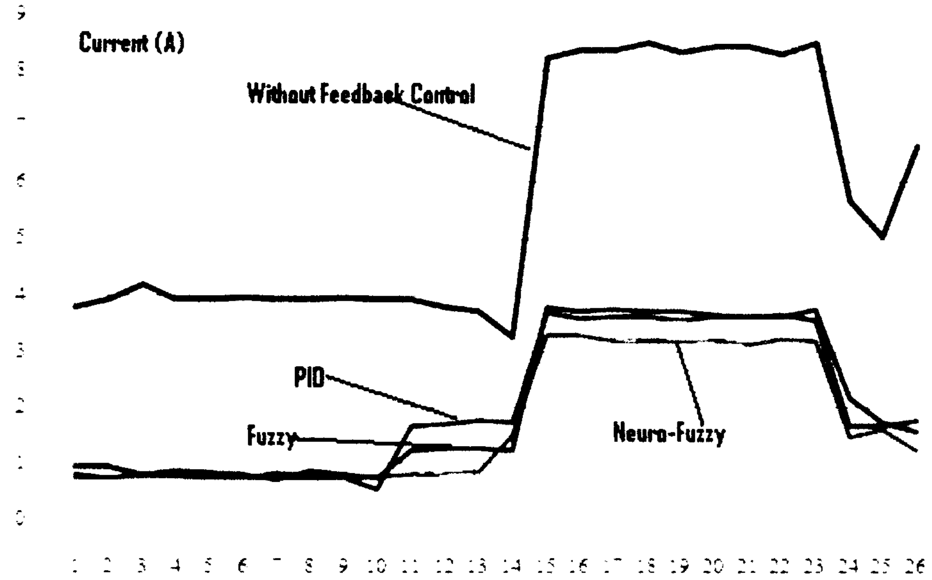

Figure 6 Comparison of power consumption

In order to compare the power consumption performance, when the machine operation using both conventional PID, fuzzy and hybrid neuro-fuzzy control, the measured current from motor was used to evaluate the operation performance. Fig6is shownthat the power consumption on waiting process, the conventional system consumption is about 3.9 amperes, for the control system with fuzzy, PID, and neuro-fuzzycontrollers consumption are about 0.7-0.8 amperes. During compression the consumption is about 8.0 amperes approxcimately.On other hand the consumption of fuzzy, PID, and a neuro-fuzzy controllers are about 3.2-3.7 amperes. The quantitative current measure is based upon the pressure tracking performance for hydraulic test rig system which shown in table 3.

Table 3. Power consumption of electric motor

Control Framework	Without Feedback control	PID	Fuzzy	Neuro-Fuzzy
(kW*hr)	2.25	0.76	0.76	0.61
Percentage	100	66.25	66.34	72.88

Table 3 shows that the inverter control with PID controller and intelligent fuzzy controller can reduce the power consumption of 66.25% and 66.34% of the conventional system.Additionally, the system is controlled with adaptive neuro-fuzzy can reduced power consumption by up to 72.88%.

Conclusion

As applications of electro-hydraulic system become increasingly widespread, the demand for low cost, high-level control performance and significant energy saving schemes gets more significant. In this paper, a adaptive neuro-fuzzy, fuzzy and PID controller is developed to improve the energy saving and pressure servo performance of the electro-hydraulic system. The proposed intelligent control schemes wereemploy to control the inverter to adjust flow of hydraulic oil of by varying an electric motor with strategically coupling with hydraulic gear pump. The experimental results showed that using anadaptiveneuro-fuzzy controller in electro-hydraulic system can reduce power consumption up to 72.88% compared to the conventional system. Furthermore, the robust performance of pressure servo can be archived from using this intelligent controller.

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