A learning control of unused energy power generation

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Abstract In recent years, the development of new clean energy without dependence on fossil fuel has become urgent. This article proposes a learning control system for power generation using a low-temperature gap which has been designed to maintain the speed of a steam turbine in a real environment. This system includes nonlinearity and the characteristics of changing parameters with age and deterioration, as in the real environment. The evaporator, condenser, and turbine systems have been modeled, and a PID control with the ability to learn, based on a BackPropagation neural network, has been designed.

Key words Learning control · BP neural network · Power generator · Low thermal gap · Evaporator · Turbine

1 Introduction

Clean energy exits in the natural world, and this energy does not emit exhaust gases when it is used. This clean energy is widely used for wind generators, solar power, and so on, whereas there is some clean energy that has not yet been used, such as the heat from hot springs or the exhaust heat from factories. Power generation with these unused clean energies can produce only a small amount of heat with low thermal efficiency because these power generators scatter the usable energy so widely. The temperature gap of unused energy is as low as 20–30°C. In contrast, the temperature gap of thermal power generation is 500°C, and the temperature gap of nuclear power generation is 200°C. The heat efficiency is also low at 3% to 4%, while the efficiency of thermal power generation is 40%. Moreover, these heat sources are scattered, and their scale is small. Therefore, it is necessary to establish a control method that is suitable for the power generation at that capacity and scale. A power generation system is composed of a water/ammonia fluid as the working fluid. A heat exchanger model and a turbine model have been built, and a PID control with an ability to learn, based on a BP neural network, has been designed.

2 Power generation using a low temperature gap

The main component of a power generation system using the low temperature gap in a closed cycle is constructed of a heat exchanger (evaporator, condenser), turbine, and pumps. The working fluid is carried to the evaporator by the pumps. It is then boiled, and the water becomes steam in the evaporator. While steam from the working fluid is passing through the turbine, the system can generate electric power by rotating the blade shaft of the turbine. The working fluid that has passed through the turbine is cooled with the cold water in the condenser and becomes liquid again. The structure of the power generation system is illustrated in Fig. 1.

2.1 Evaporator model

The evaporator is a shell-and-tube type as shown in Fig. 2. The working fluid is carried to the evaporator tank by the pump in the heat exchanger tube. Hot water circulates in the heat exchanger tube, and then the working fluid becomes steam.

Modeling assumptions

1) When the working fluid flows into the evaporator, it is preheated to the saturation temperature in the liquid phase.
2) The heat exchanger tubes are soaked by the working fluid.
3) Radiation heat from the entire evaporator is not considered. The steam pressure equations are as follows.

\[ H(s) = \frac{1 - \exp(\tau s)}{\tau s} \]  

The steam flowing from the evaporator outlet is \( \Delta Q(s) \), the change in temperature of the hot water to the inlet is \( \Delta Q_h(s) \), and the change in flow of the hot water is \( \Delta Q_h(s) \).

\[ \Delta Q(s) = \begin{bmatrix} Z_1 \\ Z_2 \end{bmatrix} \begin{bmatrix} \Delta G_h(s) \end{bmatrix} \]  

Here,

\[ Z_1(s) = \frac{\frac{K_1(1-e^{-\tau s})}{sT_e(1+sT_h)}}{1+sT_h} \]  

\[ Z_2(s) = \frac{\frac{K_2(1-e^{-\tau s})}{sT_e}}{1+sT_e} \]  

\( T_e, T_h \) are time constants, \( K_1, K_2 \) are constants, and \( \tau \) is a system constant.

2.2 Turbine model

The turbine is composed of a steam control valve and a rotor blade as shown in Fig. 3. The steam is piped from the evaporator to the turbine blade through the steam control valve. The steam control valve adjusts the flow of steam to the turbine blade. The equations of the turbine system are given below.

Working fluid steam control valve:

\[ \frac{dx_i}{dt} = K_3 \frac{v}{v_{\text{max}}}, \quad 0 \leq x_i \leq 1 \]  

Working fluid steam mass rate:

\[ \mu_T = \frac{x_1}{M_E} (\phi_E - \phi_T)^{1/2} \]  

Turbine blade speed:

\[ \frac{dv}{dt} = \frac{1}{\tau_T} \left[ \frac{\phi_E - \phi_T}{\phi_E - \phi_T - \mu_T - (1 - \epsilon) \frac{1}{v} - \epsilon v^2} \right] \]  

where \( v_{\text{max}} \) is the maximum speed of the turbine blade, \( K_3 \) is the gain, \( M_E \) is a constant parameter, \( \phi_E \) is the vapor pressure at the evaporator outlet, \( \phi_T \) is the vapor pressure at the turbine outlet, \( \tau_T \) is a system constant, \( \epsilon \) is the electric load, and \( \phi_E, \phi_T, \mu_T \) are desired values.

3 Back propagation neural network

The back propagation neural network (BPNN) is a multilayer network that consists of the input layer, the hidden layer, and the output layer. The standard structure is shown in Fig. 4.

3.1 BP algorithm step

First, the actual output of the BPNN will be obtained from the actual outputs as in Eq. 8. This is forward progress.

\[ a^{k+1} = f^{k+1}(w^{k+1} \cdot a^k + b^k) \quad k = 0, 1, \ldots, m-1 \]  

\( \alpha \) is the output of each layer, \( w \) is the weight value, \( b \) is the bias value, and \( m \) is the number of layers.

Second, the error will be generated in the output layer by a comparison between the actual output and the target output. The error function at the output layer is defined as

\[ E_p = \frac{1}{2} \sum_{k=1}^{m} (T_k - A_k)^2 \]  

\( T_k \) are the reference outputs, and \( A_k \) are the actual outputs.