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Conference Paper · November 2010

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X Triennial International SAUM Conference
on Systems, Automatic Control and Measurements
Niš, Serbia, November 10th-12th, 2010

Improved Auto-tuning PID Controller of Level in Condenser of Turbine in Thermal Power Plant Using Saturation-relay Feedback

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Abstract: ***- Properly tuned controllers should ensure correct and unobstructed functioning of the system, i.e. process. Using ideal relay as nonlinearity in process of auto-tuning gives significant errors in estimates of the ultimate gain and ultimate period. In this paper mentioned lack is overcomed by introduction saturation relay, where control system of condensate level in condenser of turbine in thermal power plant Gacko is used as a model. Due to the constant striving to reduce energy consumption, above settings are implemented in the system for which is proposed strategy which provides energy savings, i.e. includes frequency regulators.***

Key words: ***auto-tuning, PID controller, ideal relay, saturation relay, frequency regulator***

I. INTRODUCTION

Tunning PID controller is dedicated great attention due to constant striving for the satisfactory behaviour of the object. A significant progress was made by introduction nonlinearies in the form of an ideal relay in the process of controller auto-tuning [1]. However, practice has shown that in such a way, significant errors in determining the ultimate gain and ultimate period are present, because of simplifying the mathematical description of ideal relay output. Improvement was achieved by replacing the ideal ralay with saturation relay, whose output is more accurately decsribed by sine function and significanlty reduced errors [1]. In this paper, model of control system of condensate level in condensar of turbine in thermal power plant Gacko was used and it was carried out simulations of auto-tuning controller parameters using the saturation relay [7]. The resulting controller parameters are applied in the simulation system for which is proposed energy saving strategy, which includes frequency regulators. So that responses (levels as function in time) of mentioned control system were obtained for the parameters which were calculated using the ideal relay and saturation relay. In this way, the discussions about validity of some parameters in relation to the others are enabled.

A. Description of Object (Condenser)

Thermal power plant Gacko works on Clausius – Rankine principle (cycle). It is a steam cycle. The main elements of this plant are: boiler, turbine, condenser and pump, each coupled with pipes and armature.

The purpose of the cooling system in thermal power plant is the removal of condensation heat of steam expanded in the turbine and other auxiliary cooling to the enviroment. Its main components are the condenser, cooling tower and pumps. Condenser is firmly conected to the turbine and relies on springs to take its weight. In this part the exchange of heat is carring out, under constant pressure. When there is no mechanical interaction between steam and cooling water. Condenser is made as surface heat changer, in which the steam condensation is performing on the cooling surfaces, which consist of a numerous cooling tubes through which cooling water passes. In addition, condenser is place for condensate accumulation, which forms level that should be controled to be constant. In the process of heat delivering to the enviroment a substaitnal part of the water evaporates and it is compensated from the reservoir, where water is brought from an artifical lake Klinje.

Level in the condenser depends largely on the amount of fluid that come into condenser and drains off it, as shown in Fig. 1.

Technical and exploitation (nominal) data of condenser are [3]:

1. pressure: 0,035 (bar),
2. temperature: 41 (°C),
3. cooling water flow: 36000 (m^3/h),
4. condensate level: 1,2 (m),
5. dimensions: length x width x height= 8,75 x 8 x 6 (m).

II IMPROVEMENT OF CONTROL SYSTEM OF LEVEL IN CONDENSER BY INTRODUCING FREQUENCY REGULATORS

Level in condenser dependes on the amuont of steam which comes from turbine (directly and from heater for regenerative heating), supply of demineralised (DEMI) water, drain condensate and working of vacuum pumps for obtaining vacuum in condenser. Level control is achieved using two closed-loops. In first closed-loop there is the level control over valve for condensate drainage from the condenser, while in the second loop mantioned control is carring out using valve for DEMI water supply. Thus, in both closed-loops within the system, the control part of the objest is valve.

A part of the generated electrical energy in the power plant is used to drive the devices, which are necessary for the functioning of the entire system to produce electricity. These includes electric motors to drive pumps, valves and other devices in the process. Automatic control with frequency regulators instead of control using valves (what is now in the power plant Gacko) is proposed here. Therefore, the solution is controlling the pump so that it during operation gives optimal flow, i.e. its minimum value, which is necessary to keep the level of condensate in the condenser at a set value $h_{\check{z}} = 1{,}2$ (m). In that case it is very important to controlling electric motor to operate on a minimum amount of energy for driving mentioned pump, and would not be consumption in damping energy, because in this type of control, valves for flow control are not required. It is also important to note that this method does not include electric motors that drive the appropriate valves and gearboxes and encoders of valve positions so there are even greater savings. Speed control of electric motor allow the frequency regulators [1]. Fig. 1. shows that frequency regulators are introduced in both closed-loops of level control, i.e. into control loop in which the control is done by correcting the drainage of condensate from the condenser and into control loop in which the control is done by correcting the supply of demineralised water into condenser. Where are: PID – proportional – integral – derivative controller, FR – frequency regulator, EM – electric motor (asinhronous), DV – centrifugal pump for supply demineralised (DEMI) water, KP I – centrifugal condense pump first order, KP II – centrifugal condense pump second order.

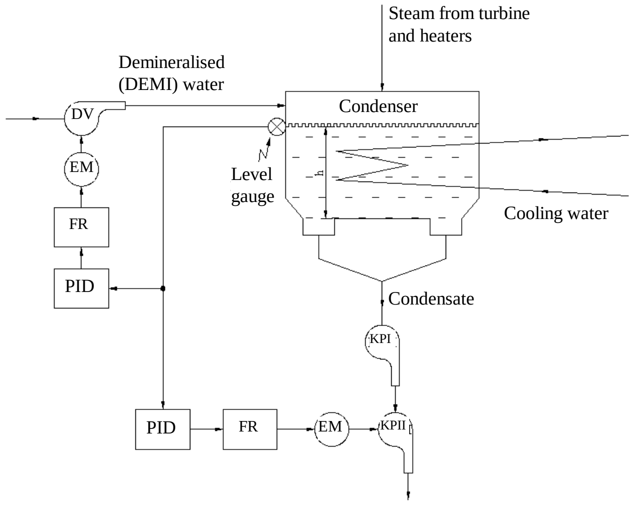

Fig. 1. Structural diagram of control system for controlling level of condensate in the condenser of turbine with strategy which includes frequency regulators [7]

III MATHEMATICAL MODEL OF THE PROCESS

Taking into account the theoretical basis of automatic control systems, mathematical model is set up knowing the structural diagram of the system, its physical principles, as well as information about the real system. After determining block diagram of all its components, we get a block diagram of the entire control system for controlling level of condensate in the condenser of turbine in the thermal power plant Gacko with applied energy saving strategy, which is shown in Fig. 2.

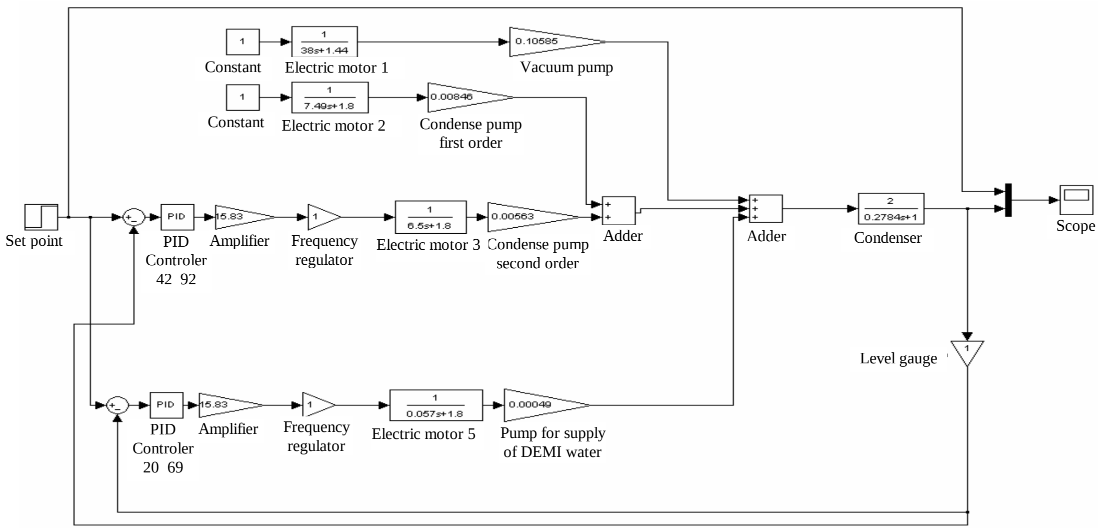

Fig. 2. Block diagram of control system for controlling level of condensate in the condenser of turbine in the thermal power plant Gacko with energy saving strategy, which includes frequency regulators [7]

In addition to the usual assumptions which simplified mathematical model of the system, here is not taken into account the dynamics of frequency regulator so for its transfer function is taken value 1 [7].

IV IMPROVEMENT OF AUTO-TUNING PID CONTROLLER USING SATURATION RELAY INSTEAD OF IDEAL RELAY

A. Auto-tuning with ideal relay

Åström and Hägglund solved the problem in determining of ultimate gain of P (proportional) controller by its repleacing with nonlinear relay, which causes the appearance of steady oscillation, because they are necessary to obtain the information about the process. Nonlinear part is relay and linear part is process, which behave as a low pass filter. Values for computing parameters according to this method are: h, a, T_u, i.e., height of ideal relay characteristic (for our case $h = 0{,}12$ (m)), amplitude of output signal of linear system, ultimate period of the oscillation, respectively. The simulation in software Matlab is carried out on mentioned model using configuration in Fig. 3.

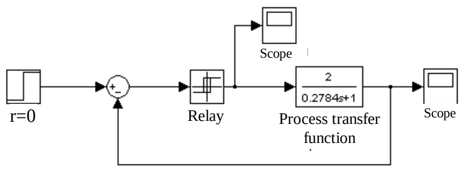

Fig. 3. Configuration which provides steady oscillation of the system

Then the output of ideal relay and process response are shown in Fig. 4. and 5. respectively.

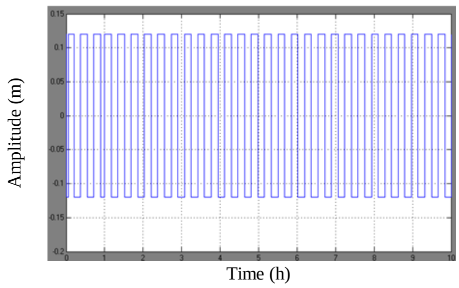

Fig. 4. Output of ideal relay

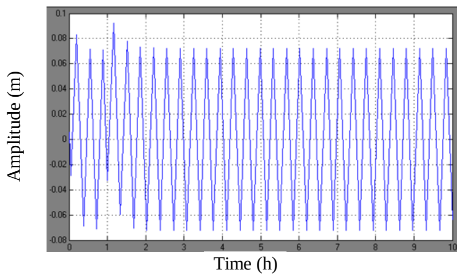

Fig. 5. Process response which was obtained by introducing relay

Increasing graphic in Fig. 5. the folowing values are determined: ultimate period of the oscillation T_u=0,347(h) and amplitude of output signal of linear system a=0,0724(m). Then the ultimate gain is given by:

$$K_u = 4h/\pi a = 2{,}11 \qquad (1)$$

Then according to Ziegler – Nichols method the controller parameters K_p =0,844 i K_i = 3,04 are computed. Hence, PI controller is tuned because this type of controlers corresponds to the first order processes, what is our condenser. The obtained controller parameters are applied in the system that is based on the energy saving strategy, whose block diagram is shown in Fig. 2. and Fig. 6. shows system response obtained by simulation.

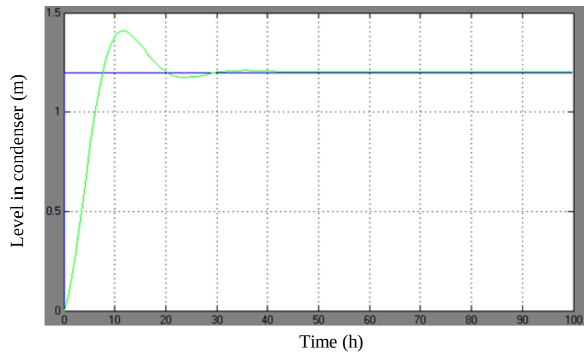

Fig. 6. Response of control system that is based on frequency regulators with controller`s parameters obtained with an ideal relay

B. Auto-tuning with saturation relay

Since in the mathematical description, the relay`s input and output are described as a sine function, it may occur errors in the auto-tuning using ideal relay, because his output is rectangular. This problem is overcome by its replacing with saturation relay, whose output is shown in Fig. 8. Simulation of saturation relay application in auto-tuning parameters of the PI controler of level is carried out using block diagram in the Fig. 7.

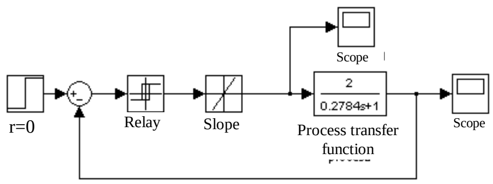

Fig. 7. Configuration for saturation relay application

Where: height of ideal relay $h = 0{,}12$ (m), the previously completed test with ideal relay gives $k_{\min} = 4h/\pi a = 2{,}11$, slope of saturation curve $k = 1{,}4k_{\min} = 2{,}954$ [7]. Then simulation gives oscillatory output as in Fig. 9.

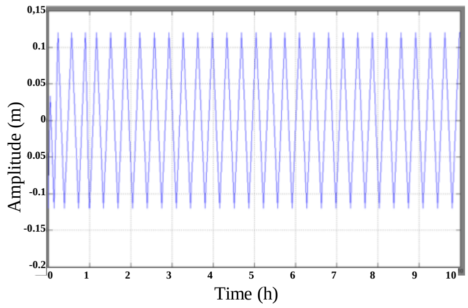

Fig. 8. Output of saturation relay

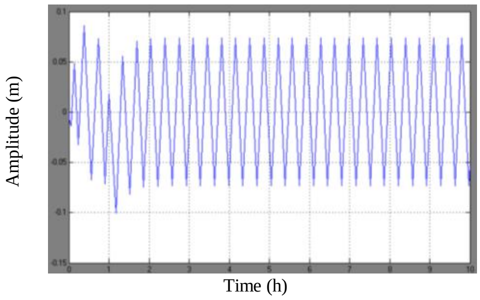

Fig. 9. Process response which was obtained by introducing saturation relay

Increasing graphic in Fig. 9. the folowing values are determined: a=0,0736(m) and $T_u = 0{,}353$ (h). In view of $k = h / h_1$, it gives slope coordinate $h_1 = h / k = 0{,}0406$ (m).

According to $\mathrm{a} > h_1$ (0,0736>0,0406) the ultimate gain can be determined by the following equation [1]:

$$K_u = \frac{2h}{h_1 \pi}\left[\arcsin\frac{h_1}{\mathrm{a}} + \frac{h_1}{\mathrm{a}}\sqrt{1-\left(\frac{h_1}{\mathrm{a}}\right)^2}\right] = 1{,}96 \qquad (2)$$

In this way, parameters of the PI controller are tuned as follows: K_p = 0,784 i K_i = 2,776.

The same procedures are performed for simulations with four larger and four smaller values of slope of saturation curve in order to prove that the best values of controller`s parameters are obtained when the calculated slope of saturation curve is applied $k = 2{,}954$. The following results are obtained.

Larger values of slope of saturation curve:

- $k = 10 \Rightarrow K_p = 0{,}812 \quad K_i = 2{,}835$
- $k = 50 \Rightarrow K_p = 0{,}84 \quad K_i = 3{,}01$
- $k = 100 \Rightarrow K_p = 0{,}868 \quad K_i = 3{,}118$
- $k = 9999 \Rightarrow K_p = 0{,}844 \quad K_i = 3{,}04$

In the case when slope is $k = 9999$, exactly the same parameters as with the ideal relay are obtained, which are expected because the slope of saturation curve tends to be vertical.

Smaller values of slope of saturation curve:

- $k = 1 \Rightarrow K_p = 0{,}4 \quad K_i = 1{,}51$
- $k = 0{,}1 \Rightarrow K_p = 0{,}04 \quad K_i = 0{,}06$
- $k = 0{,}01 \Rightarrow K_p = 0{,}004 \quad K_i = 0{,}006$
- $k = 0{,}001 \Rightarrow$ There is no oscillations in the system.

These four smaller values of slope k are taken in order to achieve the value $k = 0{,}001$ at which the oscillation does not appear. It is noticeable that the following values of slope of saturation curve k=1; 0,1 and 0,01 does not give good controller parameters K_p i K_i.

The obtained controller parameters are applied in the system that is based on the energy saving strategy, whose block diagram is shown in Fig. 2. and Fig. 10. shows system response obtained by simulation.

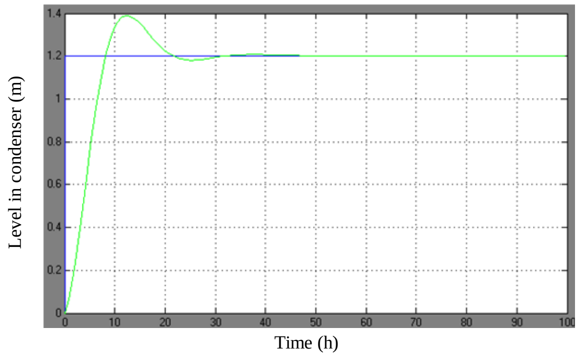

Fig. 10. Response of control system that is based on frequency regulators with controller`s parameters obtained with an saturation relay

Increasing the diagram in Fig. 6. i 10. parameters of simulated responses are determined. Comparing these parameters it is noticable that the introducing a saturation relay into auto-tuning process gives response with smaller overshoot, and the system is somewhat slower, but it has shorter settling time.

IV CONCLUSIONS

In order to improve auto-tuning of PI controller of level in condenser of turbine in thermal power plant Gacko using simulation it was tested, confirmed and proposed introduction of a saturation relay as a nonlinearity into auto-tuning process. Namely, according to obtained characteristics of system response in two mentioned cases, it was found that the better dynamic behavior of the system is achieved, if its controller was tuned using saturation relay. Because of possibility of saving considerable amounts of electrical energy it is discussed and proposed the introduction of frequency regulators into mentioned control system.

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