MODELLING OF CONTROL SYSTEM OPERATION OF COMBINED POWER AND HEAT PRODUCING PLANT

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Abstract. Nowadays the world more and more frequently meets factors that impact the mankind habitat environment. That is why it is necessary to search for renewable energy sources such as solar energy, wind energy, biomass fuels. By developing of alternative local energy sources we are increasing our independence from foreign energy suppliers. The using of biogas in combined power and heat production plants corresponds to the mentioned purposes. The control system of such CHP plant is investigated and modelled in the present article.

Key words: renewable energy, cogeneration, control system, modelling.

Introduction

The main factors that impact our living environment are:

- increased concentration of carbon dioxide in atmosphere, that creates the so called greenhouse effect;
- more frequent natural disasters, that are created by climate changes;
- decreasing of fossil energy sources etc.

One of long range energy sources in Latvia is using of biogas for Combined Heat and Power Production (CHP). At present the production of biogas in Latvian agriculture is very small, although the possible amount is rather big. For example, it is possible to obtain approximately 135.4 million m^3 biogas from agriculture waste and approx. 13.6 million m^3 from food industry per year in Latvia.

The basic documents that define the development of alternative energetics for CHP are the EU directives: “2001/77/EC: Directive on Electricity Production from Renewable Energy Sources” and “2004/8/EC: Directive on the promotion of cogeneration based on a useful heat demand in the internal energy market” [1, 2].

Biogas can be supplied to CHP equipment continuously. For successful operation in conjunction with power networks with different load, there is a necessity to provide the automatic control of the most important parameters of the cogeneration equipment. The control system operation is modelled using the computer program MATLAB subprogram Simulink.

Materials and Methods

The cogeneration plant is situated on the Latvia University of Agriculture (LUA) training and research farm “Vecauce”. Approx. 14 000 t cattle manure is produced per year on the farm (38 t per day) with moisture content 93 %. Corn is an additional source for biomass with the amount of approx. 4000 t per year (11 t h^{-1}). For such amount of raw material the tank with volume 144 m^3 and dosage tank 16 m^3 are provided.

For biogas production a special tank is provided. The raw material fermentation is going on and the biogas discharges. The process occurs in temperature approx. 38^{O}C. In this case fermentation continues 10-20 days. The volume of the biogas fermentation tank is calculated corresponding to one day dosage. If the amount of the raw material is 50 m^3 per day, the total amount has to be no less than 1500 m^3. The tank in Vecauce has total volume 2006 m^3 and the volume of the active fermentation part is 1758 m^3.

The total amount of biogas obtained from 3 500 kg raw material per day is 1400 m^3 day^{-1} or 58.3 m^3 h^{-1}, if the output from one kg dry matter is approx.0.4 m^3. On this basis the cogeneration plant for Vecauce was chosen with electric power output 260 kW and heat power output 356 kW. The efficiency for electric power producing is 0.359, heat power 0.456.

The simulation block of the cogeneration plant consists of a gas engine that is controlled, actuator, feedback and load circuit. The actuator consists of a voltage divider, servomotor and gas valve.

The main feedback operation is based on the deviation principle. It consists of speed transmitter and voltage divider. The rotation frequency of the gas engine is measured by the speed voltage generator that produces voltage depending on frequency. The produced voltage is compared with the given voltage. The difference of voltages ΔU is delivered to the controller that controls the voltage regulator. The signal from the regulator output is delivered to the servomotor that turns the gas valve for a certain angle depending on the difference. The servomotor is supplemented with stabilizing feedback.

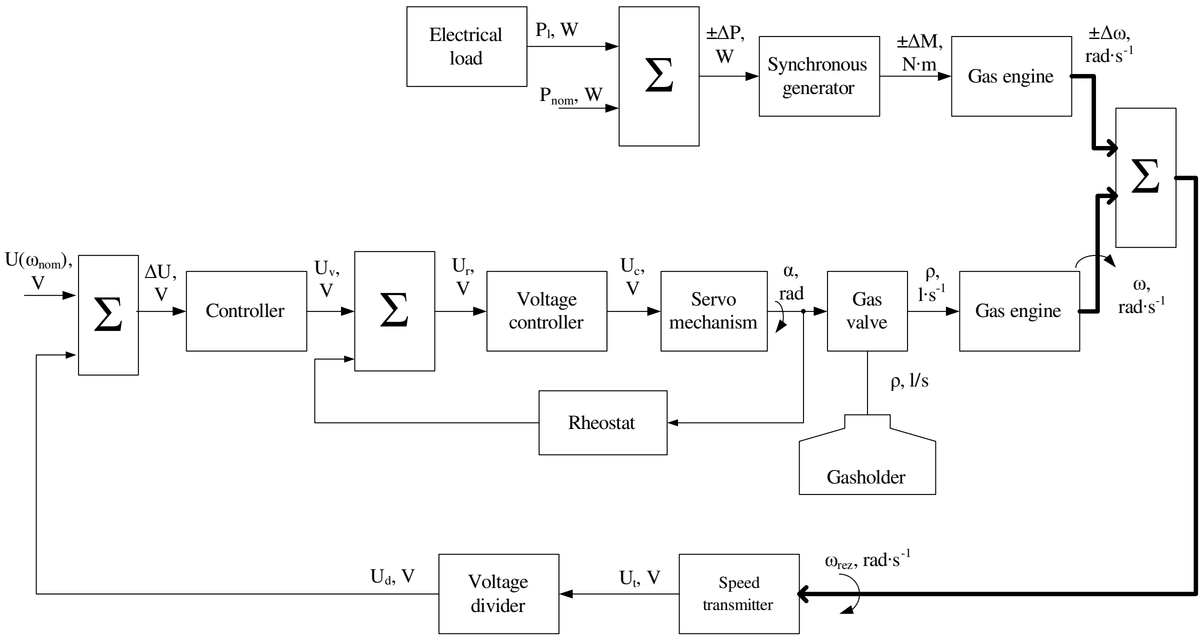

Fig. 1. **Block diagram of cogeneration plant automatic control system**

The load circuit consists of a load generator and synchronous generator. At a certain time moment the load generator creates the existing load. Then it is compared with rated power P_{nom}. Deviation impacts the torque of the synchronous generator therefore the rotation frequency of the gas engine changes, too.

Successful operation of the cogeneration plant depends on the choice of the controller type. For this it is necessary to investigate the response of open loop system to step impact. To consider open loop system component inertia, the actuator and the speed voltage generator are included in the model. For investigation of transport delay τ and time constant T of the rotation speed ω system the 10 V input voltage has been chosen [3].

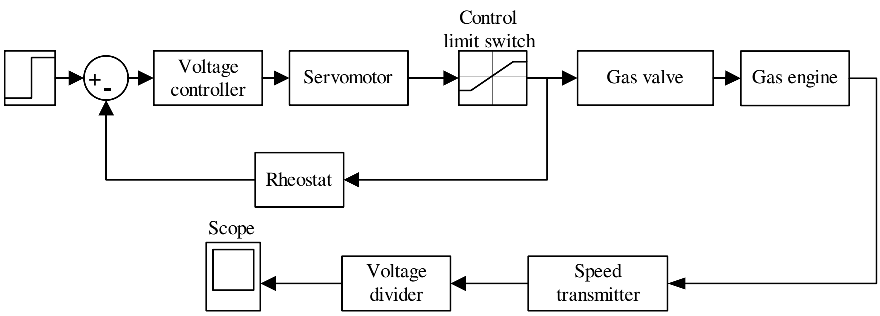

Fig. 2. **Block diagram for determination of the controller type and tuning parameters**

Table 1

Transfer functions of components

Component	Transfer function
Voltage controller	$k_V = U_{c.}/U_{vad.} = 36/10 = 3.6$
Servomotor	$W_{s.} = k_{s.}/(T_{s.}s^2+s) = 0.2/(0.1^2+1)$
Gas valve	$k_{g.} = q_{max}/\alpha_{max} = 20/2 = 10\ (1\ s^{-1})\ \mathrm{rad}^{-1}$
Gas engine	$W_{e.} = k_{e.}/(T_{e.}s+1) = 26/(1.5s+1)$
Rheostat	$k_{r.} = U_{r.}/\alpha = 0.6/2 = 0.3\ \mathrm{V} \cdot \mathrm{rad}^{-1}$
Speed transmitter	$W_{t.} = k_{t.}/(T_{t.}s+1) = 0.23/(0.05s+1)$
Voltage divider	$k_{d.} = U_{d.}/U_{t.} = 10/36 = 0.28$

where s – Laplace variable;
k – coefficients of transmission;
$U_{reg.}$ – voltage controller exit voltage, V;
$U_{vad.}$ – control signal, V;
W – transfer functions;
T – constant of time, s;
q_{max} – gas feeding maximum volume, $\mathrm{l \cdot s^{-1}}$;
α_{max} – gas valve maximum turning angle, rad;
$U_{d.}$ – voltage divider exit voltage, V;
$U_{t.}$ – voltage of the speed voltage generator, V.

Results

The curve that characterizes transient processes was obtained by simulation. The transport delay of the open loop system was $\tau = 0.67$ s and time constant $T = 2.86$ s. Applying the Lerner diagram it was established, that the most suitable control device is PID controller.

PID controller (Fig. 3) consists of proportional circuit R_1, R_2, time constant of differential circuit is $T_d = C_dR_1$, time constant of integral circuit is $T_i = C_1R_2$. The integral circuit eliminates the static error of the system. On the grounds of the Ziegler -Nichols criteria the PID controller parameters were defined.

Overshoot of the controlled rotation speed parameters will be lower than 20 % of the rotational value [4]. For the exponential transfer process the parameters of PID controller should be adjusted according to such algorithm:

$$k_p = \frac{1{,}2}{k_{obj}\tau / T}, \qquad (1)$$
$$T_i = 2\tau \quad T_d = 0.4\tau$$

where $k_p = R_2/R_1$ – transfer coefficient of proportional component;
$T_i = C_1R_2$ – time constant of integral circuit;
$T_d = C_dR_1$ – time constant of differential circuit;
τ – transport delay, s;
T – time constant, s.

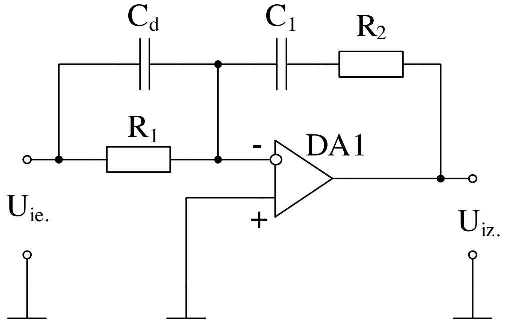

Fig. 3. **Electrical diagram of PID controller**

To determine the transfer coefficient of PID controller, it is necessary to calculate the transfer coefficient of the unit *k*.

The transfer functions of the actuator:

$$W_a(s) = \frac{W_V(s)}{1 + W_V(s) \cdot W_{r.}(s)} = \frac{1}{1/W_V(s) + W_{r.}(s)} = \frac{3.6}{0.1s^2 + s + 0.9}. \quad (2)$$

where W_a – transfer function of actuator;
W_V – transfer function of voltage controller;
$W_{r.}$ – transfer function of rheostat.

The transfer coefficient of the open loop system:

$$k = k_a \cdot k_g \cdot k_e \cdot \cdot k_{t.} \cdot k_d == 3.6 \cdot 10 \cdot 26 \cdot 0.23 \cdot 0.28 = 60.28, \quad (3)$$

where $k_{a.}$ – transfer coefficient of actuator;
$k_{g.}$ – transfer coefficient of gas valve;
$k_{e.}$ – transfer coefficient of gas engine;
$k_{t.}$ – transfer coefficient of speed transmitter;
$k_{d.}$ – transfer coefficient of voltage divider.

The tuning parameters of PID controller. The transfer coefficient of proportional circuit:

$$k_p = \frac{1.2}{k_{obj}\tau / T} = \frac{1.2}{60.28 \cdot 0.67 / 2.86} = 0.085$$

Time constant of integral circuit T_i:

$$T_i = 2\tau = 2 \cdot 0.67 = 1.34s$$

Time constants of differential circuit T_d and time constant of filter T_f:

$$T_d = 0.4\tau = 0.4 \cdot 0.67 = 0.27s$$

$$T_f = 0.05..0.2T_d \Rightarrow T_f = 0.1 \cdot 0.27 = 0.03s$$

Applying the obtained calculation results in the model and making corrections of them, the curves in Figure 4 were obtained.

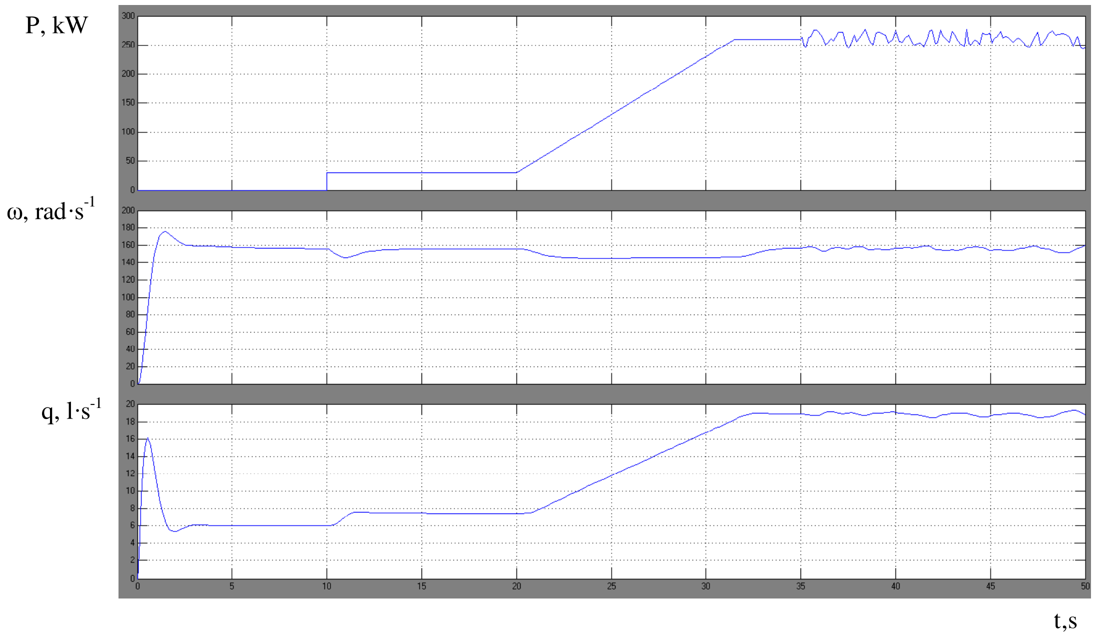

Fig. 4. **Transient curves of cogeneration plant:** *P* – electric load, *ω* – rotation frequency, *q* – consumption of biogas

Conclusions

1. On the grounds of the Lerner criteria and cogeneration plant analyses it is verified, that for control of the given system the PID control algorithm is most suitable.
2. The optimal settings of PID controller parameters are the following:
   - the transfer coefficient of proportional component $k_p = 0.085$;
   - time constant of integral circuit $T_i = 1.34$ s;
   - time constant of differential circuit $T_d = 0.27$ s;
   - time constant of filter $T_f = 0.03$ s.
3. The static error of cogeneration plant using PID controller can be eliminated. In the concrete occasion by system 5 sec. work the static error is 2.9 %.
4. The maximal overshoot of the system is 6.37 %<<20 %.

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