A quality evaluation of stabilization of rotation frequency of gas-diesel engines when using an adaptive automatic control system

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Abstract. A possibility of quality improvement of stabilization of rotation frequency of the gas-diesels used as prime mover of generator set in the multigenerator units working for abruptly variable load of large power is considered. An evaluation is made on the condition of fuzzy controller use developed and described by the authors in a number of articles. An evaluation has shown that theoretically, the revolution range of a gas-diesel engine may be reduced 25-30 times in case of optimal settings of the controller in the whole power range. The results of modelling showing a considerable quality improvement of transient processes in the investigated system during a sharp change of loading are presented in this article.

1. Introduction

An introduction of gas-diesel engines as prime movers of generating sets is one of the most perspective trends of multigenerating autonomous grids of a number of transport objects and an industry. First of all, it concerns self-contained drilling rigs where associated gas can be used as fuel of gas-diesel engines that increases their efficiency, profitability, reliability and reduces the number of hazardous emissions. To date, gas-diesel engines have been used as primary engines only in one-element generating sets because of a low revolution stability. Electricity supply of powerful consumers of a drilling platform requires the use of the multigenerating systems providing a possibility of operation of several generating sets in parallel. Such kind of mode sets stringent requirements for parameters of the electrical energy produced by generators, first of all –for frequency stability of the generated current and the voltage level. The first condition directly depends on ensuring stability of a shaft rotation frequency of a gas-diesel primary engine of the generating set (GS).

The reasons of low stability of the gas-diesel engine revealed on the basis of the analysis of specialized literature and our own full-scale studies have been described by authors in a number of works [1-4]. A considerable change of calorific values of gas under various conditions and a lack of account of an effect of turbocharging during synthesis of the regulator of gas-diesel engine revolutions is observed. Let us refer to the main of them.

IOP Conf. Series: Materials Science and Engineering **177** (2017) 012043 doi:10.1088/1757-899X/177/1/012043

2. The improved dynamic model of GDGS

Authors have offered a specified model of GDGS describing the generating set both in a statics, and in dynamics for a research of dynamic characteristics. Authors have shown [4] that the dynamic model of the gas-diesel engine owing to an effect of disturbances on loading cannot be adequately described by the mathematical models offered in the literature which are not taken in to account during turbo-charging. An offered chain diagram, describing GDGS, is shown in figure1.

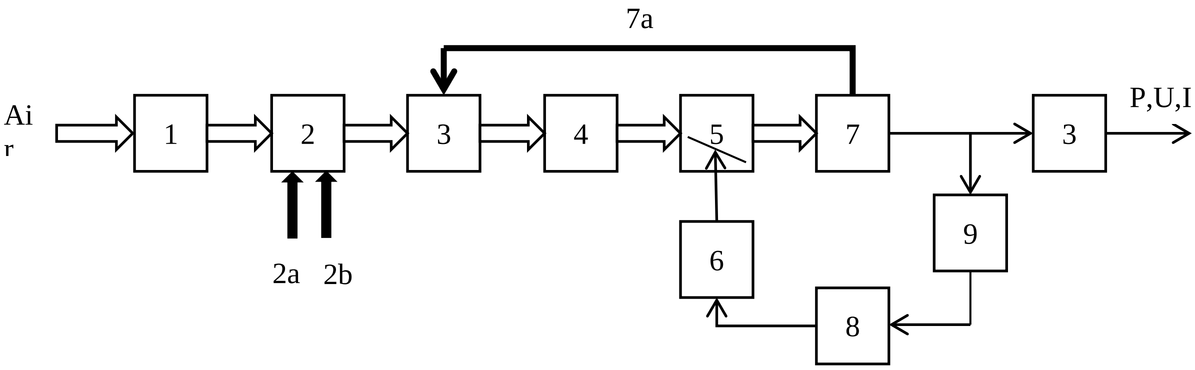

Figure1.A chain diagram of the gas-diesel generating set

1 – air filter; 2 – mixer; 2a – main piping of gas; 2b – gas piping of no-load operation; 3 – turbocharger; 4 – cooler; 5 – shutter; 6 – DC machine; 7 – cylinder block of gas diesel engine; 7a – outlet pipe of exhaust gases; 8 – regulator; 9 – Hall Effect Sensors.

This model is described in detail in [1-4].

3. Adaptive nonlinear control system of GDGS revolutions

The authors have suggested the adaptive regulator which is carrying out automatic identification of GDE parameters and adaptive correction of the PID-regulator settings of GDE [1-4] for the increase in efficiency stabilization systems of rotation frequency of gas-diesel engines (GDE) in the gas-diesel-generator set (GDGS) of the autonomous grid (AG) operating with abruptly variable loads.

The block diagram of the investigated system including the controller (C) with the tuning unit (TU) of parameters of the controller is represented in figure2.

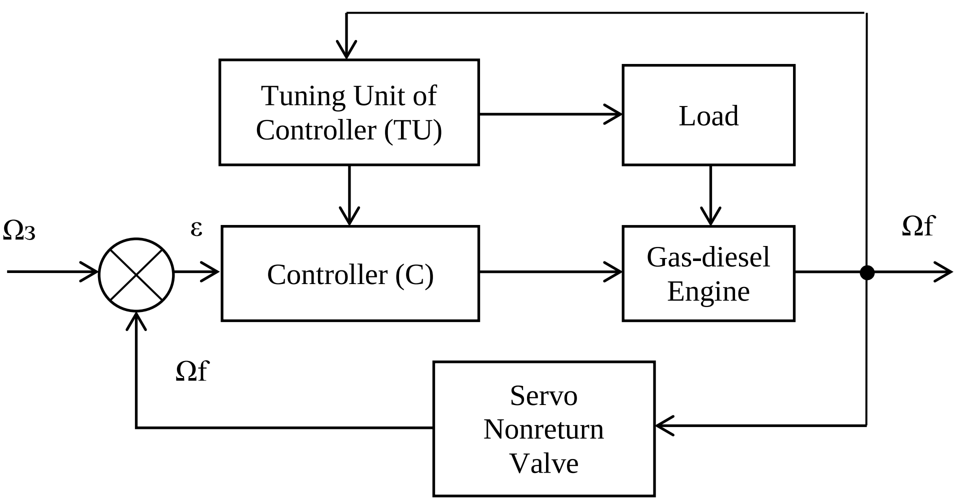

Figure 2. A block diagram of adaptive controller GDE with automatic identification of parameters: Ω_3 – assigned rotation frequency; Ω_f –actual rotation frequency; ε – error signal.

The developed identification algorithm of parameters and settings of the PID-controller uses the controlled load shedding and demanded load of GDGS with a step of 20%. Primary identification is made once during system tuning. Further, the fuzzy controller of parameters of the PID-controller is included.

The existing methodology allows providing the simple and fine PID controller tuning under a particular service condition. Further, the adjusted PID controller is capable of providing satisfactory stabilization of rotation frequency at its insignificant deviations from a specified value. But, as is well known, the quality of transient processes in the system with the PID-controller will be unsatisfactory with high probability during abrupt changes of an operating mode of GDGS or during its transition to another operating mode [4-7]. A tuning of the PID controller parameters is required under the mentioned conditions. The authors suggested a use of the controller on the basis of fuzzy logic for ensuring automatic correction of settings.

A block diagram of the possible implementation variant of the fuzzy controller for adaptive tuning of the PID controller coefficients of GDGS revolutions (during which the regular controller supplied with the GDE can also be used) is shown in figure 3.

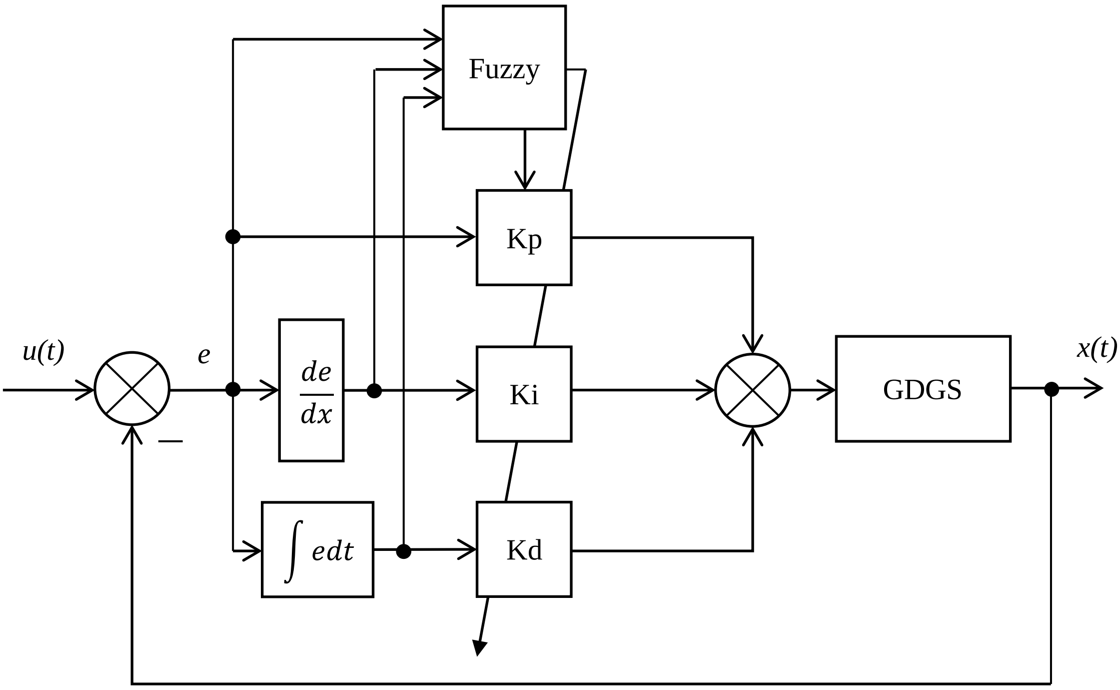

Figure 3. The use of the fuzzy controller of PID-regulator settings of rotation frequency of GDGS.

Theoretically, incorporation of automatic correction of controller settings of rotation frequency of GDGS allows expanding the range of stable operation of the latter up to emergency operation.

4. Evaluation of theoretical efficiency of stabilization of GDE revolutions during adaptive control

As it has been found in [2], really functioning GDGS can be considered as the perfect machine which is effected by the normal-mode interference with a certain [4-10] physical nature and parameters. It also may be assumed that the suggested control algorithm [2] will allow lifting significantly the stability of revolutions of GDE in all power ranges of load.

The block diagram of the GDE is represented in figure5. The normal-mode interference in the form of the destabilizing function is summed up with an output signal – the rotation speed of a GDE shaft. Let us present the description of blocks of the scheme in figure4:

$$\left.\begin{aligned} W_{\text{PID}} &= \frac{T_{\text{p}} T_g p^2 + K_{\text{p}} T_{\text{i}} p + 1}{T_{\text{i}} p}; W_y = \frac{K_y}{T_y p + 1}; \\ W_{\text{D}} &= \frac{(T_{TH} p + 1)}{\frac{T_{TH}}{1 - K_d K_{TH}} p + 1} \cdot \frac{K_d}{1 - K_d K_{TH}}; W_\omega = \frac{1/D}{\frac{T_e}{D} p + 1} \end{aligned}\right\} \quad (1)$$

Assuming $W_K = W_{PID} \cdot W_{TH} \cdot W_{\text{d}} \cdot W_\omega$,let us calculate the interference level at the output of closed loop system $f_{\omega з}$:

$$f_{\omega z} = \frac{f_\omega}{1 + W_K} = f_\omega \cdot \frac{1}{1 + W_K} = f_\omega \cdot W_{\text{Z}} \cdot$$

Interference power spectral density at the output of the closed loop

$$S_{\omega z}(\omega) = S_\omega \cdot \left| W_z(j\omega) \right|^2 = S_\omega \cdot \left| \frac{1}{1 + W_K(j\omega)} \right|^2 .$$

From the given formula, taking into account a character of linear amplitude frequency characteristic (LAFC) of the stable system for the area of effective interference cancellation, where $|W_K| >> 1$:

$$S_{\omega з}(\omega) \approx S_\omega \cdot \frac{1}{\left| W_K(j\omega) \right|^2} .$$

Let us consider now LAFC of the closed loop system in more detail. Taking into account (1), it is possible to write down:

$$W_K = \frac{T_{\text{i}} T_g p + K_p T_{\text{i}} p + 1}{T_{\text{i}} p} . \frac{K_y}{T_y p + 1} . \frac{K_g . (\text{T}_{TH} \text{p} + 1)}{\frac{\text{T}_{TH}}{1\text{-K}_{\text{y}} \text{K}_{TH}} p + 1} . \frac{1/D}{\frac{T_e}{D} p + 1} =$$

$$\frac{K_y}{D} . \frac{K_{\text{d}}}{1\text{-K}_{\text{d}} \text{K}_{TH}} . \frac{a_3 p^3 + a_2 p^2 + a_1 p + 1}{\left(b_3 p^3 + b_2 p^2 + b_1 p + 1\right) . p} . \frac{1}{T_{\text{i}} p},$$

where $a_1 = K_{\text{p}} T_{\text{i}} + T_{TH}$; $a_2 = T_{\text{i}} T_{\text{g}} + K_{\text{p}} T_{\text{i}} T_{TH}$; $a_3 = T_{\text{i}} T_{\text{d}} T_{TH}$;

$$b_1 = T_y + \frac{T_e}{D} + \frac{T_{TH}}{1 - K_{TH} K_d}; \quad b_2 = T_{\text{y}} \frac{T_e}{D} + \frac{T_y T_{TH}}{1 - K_{TH} K_{\text{d}}} + \frac{T_e T_{TH}}{D(1 - K_{TH} K_{\text{d}})}; \quad b_3 = \frac{T_{\text{y}} T_e T_{TH}}{D(1 - K_{TH} K\text{d})}..$$

According to the results of calculations of polynomial coefficients $A(a_i, p)$ and $B(b_i, p)$, it has been revealed that they actually compensate each other. At the same time, the error does not exceed in the narrow frequency range of 10 dB.

5. Quality research of rotation frequency control and power control via computer model

The general block diagram of GDGU operating in parallel is represented in figure 4. Active power allocation between GU of APS depends on the control accuracy of GDGU's revolutions.

The APS computer model with GDGU is represented in figure 4. It consists of two GDGUs operating for active and inductive load of different power (0.2 MW and 0.3 MW with the power of each GDGU equal to 0.67 MW). GDGU incorporates the following blocks: a model of the gas-diesel engine, excitation systems of the generator, switchboards, measuring units. Control of settings of regulators is carried out via virtual COM ports from the external fuzzy controller.

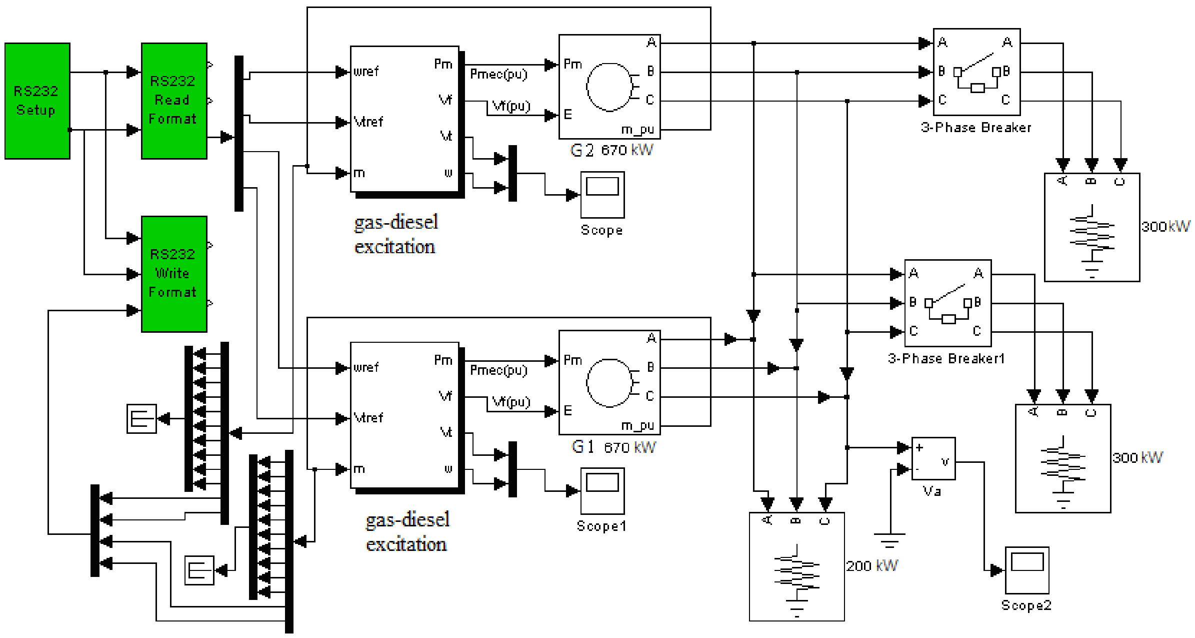

Figure4. The model of APS with two GDGUs operating in parallel.

6. Conclusion

The analysis of results shows that the use of the adaptive regulator of rotating speed of the gas-diesel engine including a fuzzy controller provides reducing of oscillations of GDGU's revolutions theoretically about 25-30 times.

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