

# Evaluation Of Rotation Frequency Gas-Diesel Engines When Using Automatic Control System

**A Zhilenkov, A Efremov**

Peter the Great Saint-Petersburg Polytechnic University  
Polytechnicheskaya, 29, St.Petersburg, Russian Federation, 195251

E mail: zhilenkovanton@gmail.com

**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 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 gas-diesel engine may be reduced at 25-30 times at optimal settings of the controller in all the power range. The results of modeling showing a considerable quality improvement of transient processes in the investigated system at a sharp change of loading are presented in this article.

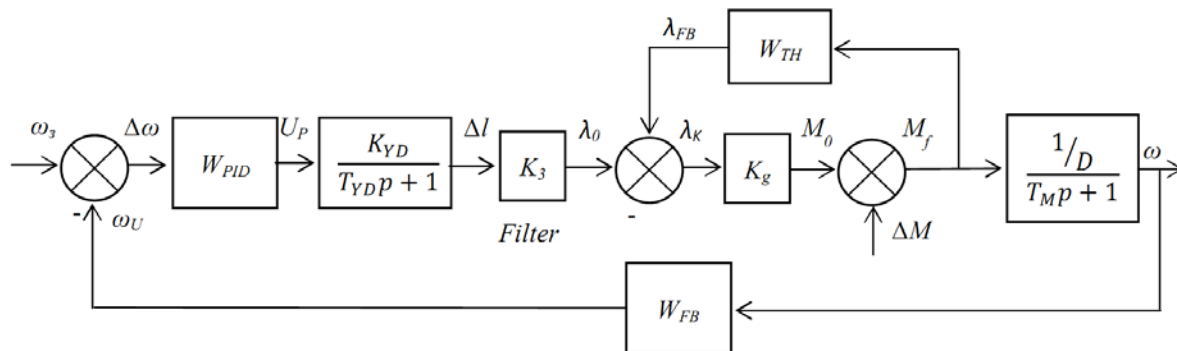
## 1. Introduction

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. The first condition directly depends on ensuring stability of a shaft rotation frequency of 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]. Analysis of published data and the problem statement.

## 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 at account of an effect of disturbances on loading can't be adequately described by the mathematical models offered in literature which aren't including an account of a turbo-charging. Its block diagram represented in fig. 1.



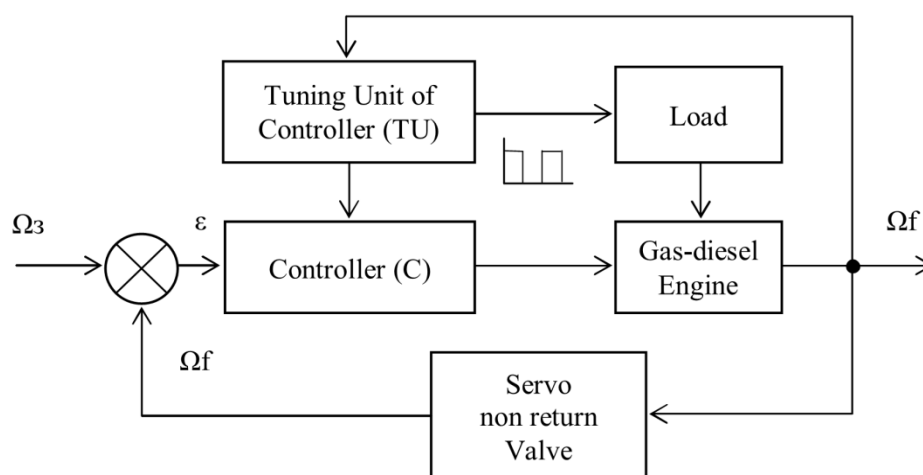


**Figure 1** – A block diagram of GDGS:  $W_{PID}$  – a block with a transmissibility of PID controller;  $D$  – coefficient allowing self-regulating properties of prime mover;  $T_M$  – equivalent engine time constant allowing lag of flyweight masses of engine and a rotor of a generator;  $K_g$  – element gain displaying conversion of flow of gas-air mixture while shaft torque;  $M$  – shaft torque;  $\omega_3$  – preset speed;  $\omega_u$  – true speed;  $\Delta\omega_3$  – speed error;  $U_{II}$  – output voltage of PID controller;  $K_{YD}$  – block gain, describing travel of fuel rack;  $T_{YD}$  – time constant of block, describing travel of fuel rack;  $\lambda_0$  – quantity of gas-air mixture;  $\lambda_{OC}$  – gas-air mixture being returned trough turbocharger system;  $\lambda_K$  – quantity of gas-air mixture, being taken for establishing of shaft torque;  $M_0$  – torque, being established by gas-diesel engine;  $\Delta M$  – resistance torque about the shaft, established by adjusent gas-deisel generator;  $M_f$  – net moment about the shaft;  $\omega$  – shaft rotation speed;  $W_{TH}$  – turbocharger block.

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

Adaptive nonlinear control system of GDGS revolutions. 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 [2-4] for increase in efficiency stabilization systems of rotation frequency of gas-diesel engines (GDE) in 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 on fig. 2.



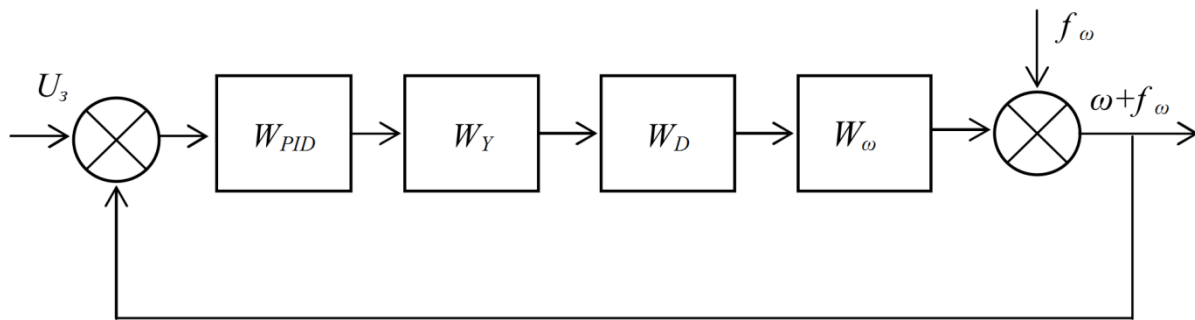
**Figure 2** – A block diagram of adaptive controller GDE with automatic identification of parameters:

$\Omega_3$  – assigned rotation frequency;  $\Omega_f$  – actual rotation frequency;  $\varepsilon$  – error signal

### 3. Evaluation of theoretical efficiency of stabilization of GDE revolutions at adaptive control

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

The block diagram of the GDE is represented in the figure3. 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.



**Figure 3** – The block diagram of the Gas diesel engine  $W_{PID}$  – PID controller of GDE rotation frequency;  $W_Y$  - output signal amplifier of PID controller;  $W_D$  – DC machine(flap controller);  $W_\omega$  – block describing dependence of revolutions of gas-diesel engine on rotation angle of flap;  $U_3$  - output signal of speed setter;  $f_\omega$  – normal-mode interference;  $\omega$  –rotation frequency of GDE.

Let's present the description of blocks of the scheme fig. 5:

$$\left. \begin{aligned} W_{PID} &= \frac{T_p T_g p^2 + K_p T_i p + 1}{T_i p}; W_Y = \frac{K_y}{T_y p + 1}; \\ W_D &= \frac{(T_{TH} p + 1)}{\frac{T_{TH}}{1 - K_D K_{TH}} p + 1} \cdot \frac{K_D}{1 - K_D K_{TH}}; W_\omega = \frac{1/D}{\frac{T_E}{D} p + 1} \end{aligned} \right\} \quad (1)$$

Assuming  $W_K = W_{PID} \cdot W_Y \cdot W_D \cdot W_\omega$ ,

calculate interference level at the output of closed loop system  $f_{\omega 3}$ :

$$f_{\omega 3} = \frac{f_\omega}{1 + W_K} = f_\omega \cdot \frac{1}{1 + W_K} = f_\omega \cdot W_3 \quad (2)$$

Interference power spectral density at the output of closed loop

$$S_{\omega 3}(\omega) = S_\omega \cdot |W_3(j\omega)|^2 = S_\omega \cdot \left| \frac{1}{1 + W_K(j\omega)} \right|^2 \quad (3)$$

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

$$S_{\omega 3}(\omega) \approx S_\omega \cdot \frac{1}{|W_K(j\omega)|^2} \quad (4)$$

Let's consider now LAFC of the closed loop system more detail.

The calculated values of coefficients  $a_i$  and  $b_i$  and for all load range of GDGS are tabulated in table 1.

**Table 1**

The calculated values for the coefficients  $a_i$  and  $b_i$  the load P

P, %	0	20	40	60	80	100
$a_i, b_i$						
$a_3$	0	16.3	12.1	8.8	6.9	5.5
$a_2$	0	54.6	41	27.76	23.5	18.9
$a_1$	0	1.1	1.86	2.22	2.0	1.7
$b_3$	0	0.1	0.19	0.4	0.5	0.3
$b_2$	0	2.2	4.0	7.8	10.3	6.3
$b_1$	0	4.5	5.0	6.4	6.6	5.6

According 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 doesn't exceed in the narrow frequency range of 10 dB. For this reason equation for evaluation of efficiency of interference cancellation  $f_\omega$  in diesel revolutions  $W_k$  may be present as:

$$W_K \approx \frac{K_y K_D}{D(1 - K_D T_{TH})} \cdot \frac{1}{T_i p} = \frac{K_E}{T_i p} \quad (5)$$

Transmissibility of closed loop system has the form of:

$$W_3(p) = \frac{1}{1 + W_K(p)} = \frac{T_i p}{T_i p + K_E} = \frac{\left(\frac{T_i}{K_E}\right)}{\frac{T_i}{K_E} p + 1} \quad (6)$$

Interference power spectral density in output revolutions of engine.

$$S_{\omega Z}(\omega) = S(\omega) \cdot \frac{\left(\frac{T_u}{K_E} j\omega\right)^2}{1 + \left(\frac{T_l}{K_E}\right)^2 \omega^2} \quad (7)$$

Variance of output signal – is calculated from equation used for calculation of correlation function:

$$R_{out}(\tau) = \int_{-\infty}^{+\infty} S_{\omega Z}(\omega) e^{-j\omega\tau} d\omega \quad (8)$$

which for  $\tau = 0$  is rearranged to the form:

$$R_{out}(0) = \sigma_{out}^2 = \int_{-\infty}^{+\infty} S_{\omega Z}(\omega) d\omega \quad (9)$$

Since at values  $\omega_1$ , for which  $\left(\frac{T_l}{K_E}\right)^2 \omega^2 \gg 1$ ,  $W_Z(j\omega) = 1$ , then spectrum of output parameter is influenced only by low frequency band for which

$$W_Z(j\omega) = \left( \frac{T_I}{K_F} \right)^2 \omega^2 \quad (10)$$

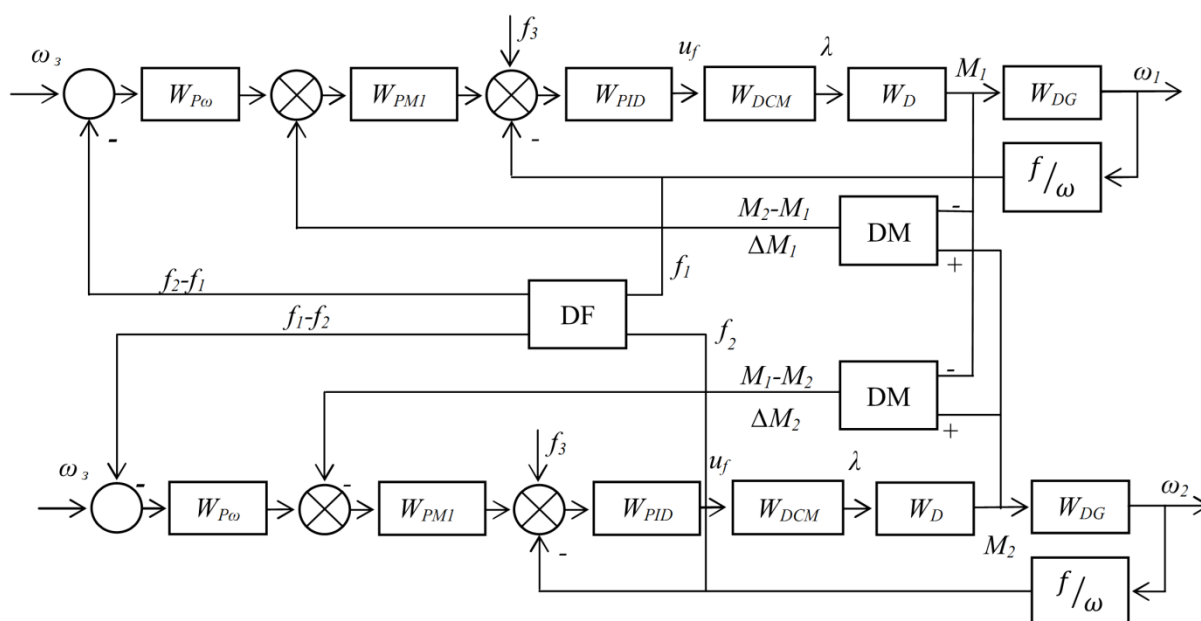
In view of stated variance of output signal - with consideration of value  $S(\omega)$  may be calculated by means of:

$$R_{\text{out}}(0) = \sigma_{\text{out}}^2 = \frac{1}{2\pi} \left( \frac{T_I}{K_E} \right)^2 \int_{-\infty}^{+\infty} \frac{\sigma_{\text{in}}^2 \alpha}{\omega^2 + \alpha^2} \cdot \frac{d\omega}{\omega^2} = \left( \frac{T_I \cdot \sigma_{\text{in}}}{\sqrt{2} \cdot K_E \cdot \alpha} \right)^2 \quad (11)$$

Thus it has been revealed that it will be possible to reduce a range of gas diesel engine revolutions for the whole power range at optimum tuning of PID controller 25-30 times.

#### 4. Quality investigation of frequency regulation of rotation and power on computer model

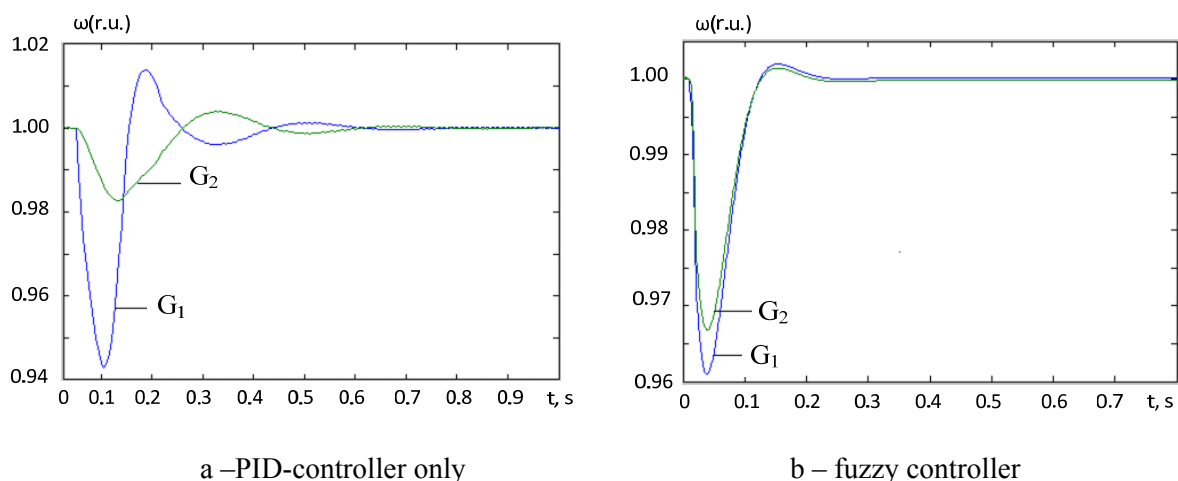
The general block diagram of GDGS connected in parallel is provided in fig. 4. Allocation of active power between GU of automated power system (APS) depends on the accuracy of regulation of turns of GDGA. The general block diagram of GDGU in parallel is represented in fig. 4. active power allocation between GU of APS depends on the control accuracy of GDGU's revolutions [5-9].



**Figure 4** – The block diagram of parallel connection of two GDGUs:  $W_{PO}$  – frequency rotation control block of GDE;  $W_{PM1}$  и  $W_{PM2}$  – power control block of 1<sup>st</sup> and 2<sup>nd</sup> GDE; DCH- frequency sensor; DM – power sensor ; M - torque;  $f$  – rotation frequency

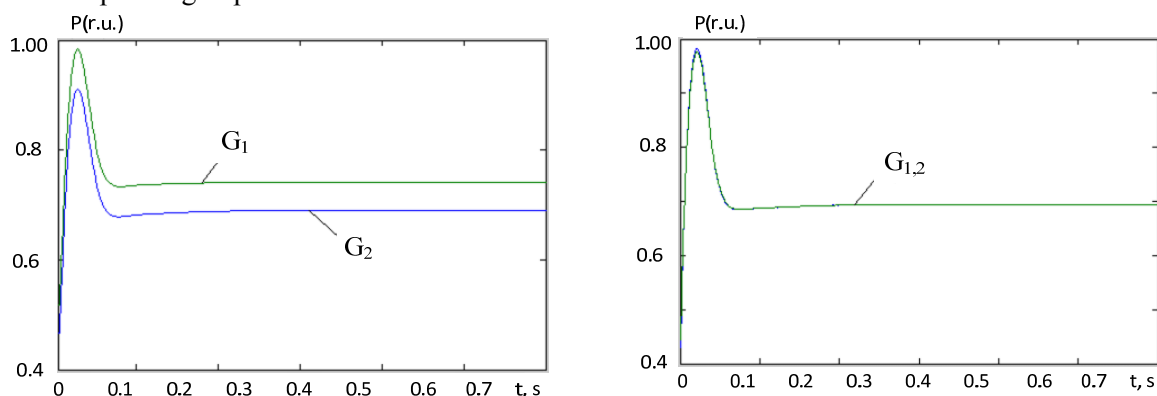
It consists of two GDGUs operating for active and inductive load of different power (0.2 MW and 0.3 MW at the power of each GDGU 0.67mvt). GDGU incorporates the following blocks: model of the gas-diesel engine, excitation systems of the generator, switchboards, measuring units. Control of settings of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

Results of a research of frequency stabilization process of GU's rotation G1 (generator 1) and G2 (generator 2) are presented in fig. 8, while abrupt change in loading. It is visible from diagrams that the use of the fuzzy controller allows improving qualitatively a stabilization process of revolutions.



**Figure 5** – Stabilization of GDGU's revolutions.

Results of a transient process research of active power control generated by generator units operating in parallel G1 and G2 are given in fig. 6. Transient power process is caused by oscillations of GDGU's revolutions at abrupt change in load. It is visible from diagrams that use of the fuzzy controller allows to improve qualitatively the accuracy of distribution of active power between GDGUs operating in parallel.



**Figure 6** – The analysis of the adaptive controller stabilizes expected value of frequency oscillations at the preset value of 50 Hz

Irregularity in power distribution when static and dynamic made no more than 5% that, by a long short is in limits which don't exceed standards, being specified by classification societies.

Frequency deviations of the voltage being generated didn't exceed values of  $\pm 0.2$  Hz being admitted by the Register.

Time of transient process didn't exceed 3s, overshoot hasn't exceeded 2%, maximum deviation of revolutions in transient processes didn't exceed 4%.

## 5. Conclusion

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

The mathematical analysis and computer modeling showed that worked out methods and devices of automatic control and regulation of GDGUs operating in parallel increase stability of their revolutions and accuracy of proportional allocation of the power being returned by them, providing a possibility of effective and safe operation of GDGU in a parallel as a part of APS.

## References

- [1] Nyrkov A, Sokolov S, Zhilenkov A, Chernyi S 2016 Complex modeling of power fluctuations stabilization digital control system for parallel operation of gas-diesel generators. 2016 IEEE NW Russia Young Researchers in Electrical and Electronic Engineering Conference (EIconRusNW),. 636-640. doi: 10.1109/EIconRusNW.2016.7448264
- [2] Zhilenkov A, Chernyi S 2015 Investigation performance of marine equipment with specialized information technology, *Procedia Engineering* 100 1247–1252
- [3] Zhilenkov A 2015 Improving the efficiency of automatic control systems of power quality of stand-alone power systems. *EasternEuropean Journal of Enterprise Technologies* 6 (9) 10–16
- [4] Chernyi S and Zhilenkov A 2015 Modeling of complex structures for the ship's power complex using XILINX system. *Transport and Telecommunication* 16 (1) 73–82
- [5] Chernyi S 2016 Use of Information Intelligent Components for the Analysis of Complex Processes of Marine Energy Systems. *Transport and Telecommunication Journal*, 17 (3) 202–211
- [6] Kutateladze S S 1979 Fundamentals of the heat transfer theory Atomizdat 415
- [7] Delaur M C, Chan V S, Murray D 2003 B A simultaneous PIV and heat transfer study of bubble interaction with free convection flow *Experimental Thermal and Fluid Science* 27 911–926
- [8] Kitagawa A, Uchida K, Hagiwara Y 2009 Effects of bubble size on heat transfer enhancement by sub-millimeter bubbles for laminar natural convection along a vertical plate *International Journal of Heat and Fluid Flow* 30 778–788
- [9] Nyrkov A, Budnik V, Sokolov S, Chernyi S 2016 The Algorithm of Development the World Ocean Mining of the Industry During the Global Crisis. *IOP Conference Series: Materials Science and Engineering* 142 012121