Optimization of the Speed Controller in Gas Diesel Device Including in the Autonomous Electric Power System

MAHMOUD M.S. AL-SUOD
Department of Electrical Power Engineering and Mechatronics
TafilaTechnical University
Tafila -11660
Jordan
m.alsoud@ttu.edu.jo

USHKARENKO OLEKSANDR
Theoretical Electrotechnics and Electronic Systems
Admiral Makarov National University of Shipbuilding
54058 Nikolaev, Central st., 3
UKRAINE
maestrotees@gmail.com

Abstract: - The work consists of development of the clarified model of a gas-diesel device by taking into account its design features and the influence of the turbo-supercharger. The analysis of the influence of the turbine on the physical processes occurring in the gas-diesel device, on the basis of which positive feedback on the torque on the shaft of the gas-diesel device is introduced, has been carried out. The process of parametric optimization of the PID-controller of the gas-diesel device has been automated to ensure high performance of the control quality in dynamic modes of its operation. As a result of modeling, oscillograms of transients before and after optimization of the controller have been obtained.

Key-Words: - power station, gas diesel engine, PID-controller, optimization .

Received: January 17, 2019. Revised: March 18, 2019. Accepted: May 20, 2019. Published: June 1, 2019

1 Introduction

Gas diesel engines (GD) are widely used for backup power supply systems, despite one of its major drawbacks - the instability of speed at low loads and at idle mode. Analysis of the results obtained by many scientists showed that the issues of ensuring the quality of electricity in autonomous electric power systems (AEPS) become particularly relevant due to the constant increase in the number of different non-linear pulsed loads. The problems of creating models for researching processes of control in AEPS, modeling emergency situations, solving problems for optimization of the composition and predicting the operating modes of AEPS, calculating the operating modes of power systems are widely studied in leading research centers, and described in works [1-3]. In work [1], an approach for modeling the processes of controlling electric power systems has been proposed. However, modern methods of modeling distributed control systems with elements of different physical nature (continuous control object and discrete controlling part), which include AEPS, are not considered sufficiently. In works [2, 3], there have been proposed ways to reduce the fuel consumption by diesel devices, but it did not address the issue of ensuring the quality of electricity. In work [4], the authors developed a method for optimizing the composition of diesel generator sets to improve the AEPS energy efficiency, but they did not address the issues of ensuring high quality control of individual power units to improve the quality of electricity. Existing models of diesel units [5-7], which could be used to optimize the speed controller, contain a number of assumptions and simplifications, such as the absence of a turbo-supercharger and feedback that takes into account the effect of turbocharging on the operation of the gas-diesel device. In other words, these models do not fully reflect those physical processes and phenomena that occur in real gas-diesel devices in dynamic operating modes, that does not allow such models to be used to address the issues of parametric optimization of the speed controller. In work [8], ways of reducing the magnitude of fluctuations in the speed of a gas-diesel device were proposed, but the results obtained refer to the static mode of operation of a power plant with a constant load. However, on the whole, this problem remained unsolved, which makes it difficult to ensure the parallel operation of several gas-diesel generating devices (GDGD). In this regard, the vital task is to develop a clarified dynamic model of the gas-diesel device and parametric optimization of the speed of the gas-diesel device

2 Problem Formulation

is to clarify the dynamic model of a gas engine taking into account the influence of a turbo-supercharger, identify significant nonlinearities leading to instability of speed and develop and solve the problem of parametric optimization of the speed controller to reduce the overcontrolling value and the time of the transition process, and as a result, ensure the stability of the frequency of the voltage in the autonomous electric power system.

3 Main material

Fig. 1 shows a functional diagram of a gas diesel device (GD), taking into account the interrelation of elements.

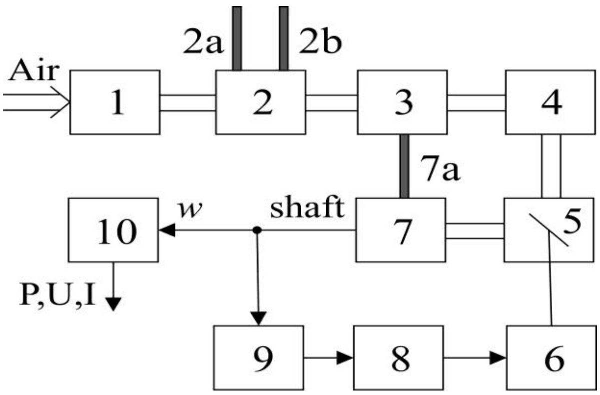

Fig. 1. Functional diagram of gas diesel device

The air flow through the air filter 1 is fed to the mixer 2 to which gas is supplied via gas pipes 2a and 2b. The main flow of gas is supplied through pipe 2a, and the gas required for maintaining idle mode is supplied through pipe 2b. After the mixer, the gas-air mixture is withdrawn by a turbo-supercharger 3, from the output of which the mixture is fed through the cooler 4 and the adjustable valve 5 to the engine cylinder block 7. The turbo-supercharger is powered by the exhaust gases that enter it through the outlet pipe 7a.

The valve is controlled by a DC motor 6, and the latter is controlled through a pulse-width controller from a signal of PID-controller 8, made using microprocessor technology. As a speed sensor, a Hall sensor 9 is used, which generates 240 pulses per round of the flywheel. The beginning of each round is fixed by the Hall sensor.

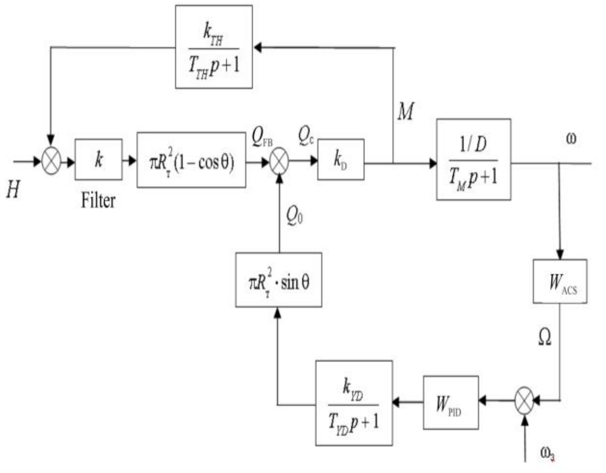

Fig. 2. Structure diagram of gas diesel device

In accordance with the description of the work of the GDGD, fig. 2 shows a structure diagram showing the peculiarity of the work of the GD both in statics and in dynamics. The PID controller conventionally represents by the transfer function WPID. It forms amplitude frequency curve of the single-loop closed system. The engine controlling the valve together with the valve itself is presented in the form of aperiodic link of the first order.

$$W_D = \frac{k_{YD}}{T_{YD}p+1} \tag{1}$$

The input parameter of the link is the signal from the output of the PID controller, and the output parameter is the volume of the gas-air mixture Q0. Actually GD is represented in the form of two links. Amplifying link kD, representing the conversion of the flow of the gas-air mixture (the volume of the gas-air mixture per unit time) at the time on the shaft M and the inertial link of the first order.

$$\frac{1/D}{T_M p+1}=\frac{1/D}{\frac{T_E}{D}p+1}. \quad (2)$$

The link establishes the interrelations between the rounds on the shaft and the magnitude of the torque. The parameter D which is a coefficient taking into account the self-regulating properties of the primary engine, according to a number of references [5, 6], varies in the interval (0.4-1); TE is the equivalent time constant of the engine, which takes into account the inertia of the centrifugal masses of the engine itself and the generator rotor.

The gas-air mixture Q0, which is formed by mixing the air flow with the gas, flows through the turbo-supercharger and cooler, through the valve to the engine input. It is characterized by the speed of movement Vc and calorific value q. During the TC cycle, the engine consumes the volume of the gas-air mixture Qc:

$$Q_c = V_c \cdot S \cdot T_C, \quad (3)$$

where S is the cross section of the pipeline through which the gas-air mixture moves.

Thus, for the cycle of work, the energy EC is supplied to the engine:

$$E_c = Q_c \cdot q. \quad (4)$$

The energy delivered by the engine to the load EL is related to the supplied EC through the efficiency factor η.

$$E_c \eta = E_L. \quad (5)$$

From the other side

$$E_L = P \cdot T_C = M \cdot \Omega \cdot T_C, \quad (6)$$

where M is the torque on the engine shaft; Ω – rounds of the engine shaft.

Thus, using (3) – (6) we find:

$$V_c \cdot S \cdot q \cdot \eta = \cdot M \cdot \Omega, \quad (7)$$

or, given that the load of gas engines are synchronous generators, which must have a stable frequency of rotation Ωn, we find:

$$M = \frac{S \cdot q \cdot \eta}{\Omega n} V_c = k_D \cdot Q_c \quad (8)$$

where $k_D = \frac{q \cdot \eta}{\Omega_н \cdot T_C}$ – engine conversion factor.

The volume of gas supplied is determined by the cross section of the pipeline πRP2 (RP is the radius of the pipeline) taking into account the angle of the air valve θ relative to the closed state, as well as the speed of its flow:

$$Q_c = Q \cdot [\pi R_P^2 (1-\cos\theta)], \quad (9)$$

where Q is the maximum possible volume of the gas-air mixture per cycle of the engine work.

Thus, the air valve performs non-linear conversion of the opening angle into the volume of the gas-air mixture.

Linearizing (9) in the vicinity of the working point we find:

$$\Delta Q_c = \frac{\partial Q_c}{\partial Q}\Delta Q_{FB} + \frac{\partial Q_c}{\partial \theta}\Delta\theta, \quad (10)$$

$$\frac{\partial Q_c}{\partial Q} = \pi R_P^2 (1-\cos\theta), \quad (11)$$

$$\frac{\partial Q_c}{\partial \theta} = Q_0 \cdot \pi R_P^2 \sin\theta. \quad (12)$$

Since the system of stabilization of rounds of the GD Ωn is static, then the PID controller in existing systems is usually adjusted so that at loads close to nominal (M≈ (0.7 ÷ 1) Mn), the static error ΔΩ does not go beyond the approved standard limits. Therefore, the PID controller provides the classic desired log-magnitude curve, which is shown in fig. 3 (line 1).

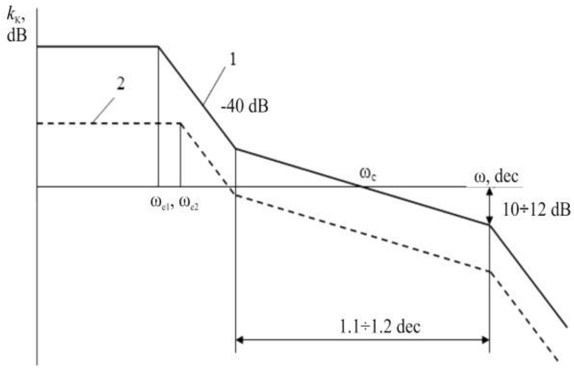

Рис. 3. Desired log-magnitude curve

This leads to the fact that when unloading the engine, kK decreases, and the desired log-magnitude curve is shifted in level, and in idle mode it goes into an unstable mode (Fig. 3, line 2) In addition, the time constant TE/D with decreasing load will decrease, which will lead to an increase in the conjugation frequency ωE and a decrease in the interval with a inclination of 40 dB / dec.

The result of the analysis of the properties of a gas diesel device was the compilation of a dynamic model of the GD, implemented in the Matlab&Simulink system (Fig. 4). This model includes the engine itself, the fuel supply system, feedback per shaft rounds, feedback per power (turbo-charging), the load on the gas-diesel shaft, the sequential correction device, and power meters on the gas-diesel output.

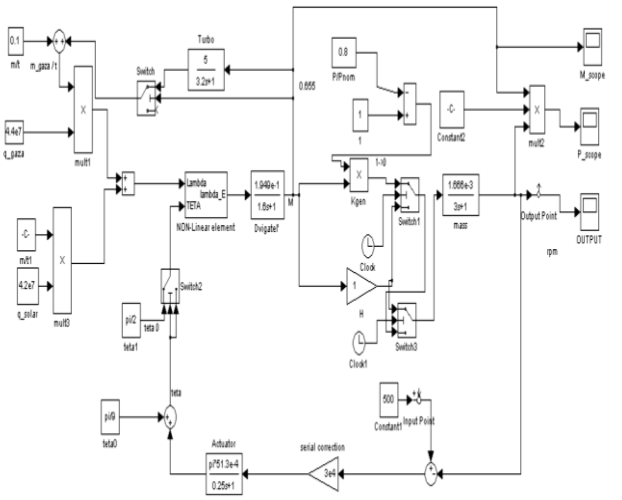

Fig. 4. Dynamic model of the gas diesel device

Gas diesel is presented in the form of a transmission coefficient kD and an aperiodic link, which takes into account the inertial properties of the centrifugal masses of both the engine itself and the generator rotor attached to it (mass). The rounds sensor is represented as an aperiodic link, since the binary counter cyclically performs integrating properties - counting the number of pulses per round of the flywheel. The time constant of such link is determined by the number of pulses per round and the frequency of rotation of the flywheel. This is a fairly high frequency link and its effect on the dynamics of the engine can be ignored.

The volume of gas at the output of the gas diesel device is changed by the throttle valve. The dependence of the volume of fuel entering the gas-diesel device on the angle of inclination of the throttle valve is a non-linear relationship. The implementation of this nonlinear element (NON-linear element) is shown in Fig. 5.

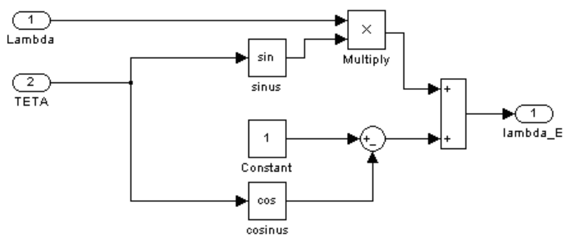

Fig. 5. Implementation of non-linear element

The model also takes into account one design feature of gas diesel. It consists in the fact that after the air valve the gas-air mixture moves along a sufficiently long pipe to the engine cylinders. In different engines, the mixture is supplied to the cylinders according to different schemes. However, in most cases, the valve is located at one end of the suction pipe and, naturally, the mixture is fed into different cylinders with a different delay. Such a delay can be taken into account either by a link with a pure delay, or by an aperiodic link with a time constant equal to the average delay in supplying the mixture to the cylinders.

In the model shown in fig. 4, the turbocharger is represented by positive feedback, which contains a switch (Switch3) activating this module in high power mode and an aperiodic link (Turbo) that takes into account the inertial properties of the turbine. In general, the model shown in Fig. 4, is a stabilizing system, since its main task is to bring the shaft speed to the value specified at the input of the control system (W_nom) [1, 2]. The whole system is covered by the main feedback. The signal from the system output goes to the main adder unit, where it is subtracted from the constant indicating the required shaft rotation frequency, and generates an error signal, which the control system fulfills.

The control system is a serial correction device (Serial correction) and an actuator (Actuator) which is the actuation device that rotates the throttle valve. The system takes into account the fact that at idle mode gas-diesel consumes a small volume of fuel, and the throttle valve is turned at some small initial angle (teta0), and the maximum angle of rotation of the valve can be 90o (teta1), switched by the switch Switch2 [3].

In the gas diesel model shown in fig. 4, the k2 and Nagruzka modules reduce the system gain ratio, and by changing this coefficient we simulate the presence of load on the gas-diesel output. During the simulation, the load is supplied not instantly, but some time after the system starts working. The time is measured by the clock unit; the load connection time is specified in the Switch1 parameters.

One of the main objectives of the study is to choose a method for stabilizing the rounds of the gas engine. Most often in solving the problems of automation proportional-integral-differential (PID) control is used. With PID control, the control signal depends on the difference between the measured parameter and the specified value, on the integral, on the difference, and on the rate of change of the parameters. As a result, the PID controller ensures the state of the actuator (intermediate between on or off), at which the measured parameter is equal to the specified one. As the state of the actuator is stabilized, the accuracy of maintaining a parameter in the system is increased by ten folds. Thus, this law of control ensures accuracy.

The PID controller coefficients of the gas engine model are adjusted using the Ziegler-Nichols method. The calculation of the optimal parameters of the PID controller occurs automatically by the formula method, depending on the control object and the selected optimality criterion. In order to choose the PID controller coefficients, you can use various methods of the theory of nonlinear systems or mathematical modeling. For the dynamic optimization of control systems during their simulation, the nonlinear control design (NCD) software package for building nonlinear control systems, which is part of the BlockSets Simulink toolkit, is used. The NCD Blockset / Simulink package provides the possibility to implement a dynamic optimization method using the special NCD Output tool, which automatically adjusts system control parameters based on user-defined limits. The capabilities of NCD Output allow you to optimize model parameters and values of control variables without directly analytically solving a system of differential equations using one of the built-in methods for finding the extremum of nonlinear functions of many variables: fminsearch, patternsearch, fmincon

At given structure of the control object and the known uncertainties of its parameters, it is necessary to find the values of the coefficients Кр, Ki and Kd of the controller. The values of the coefficients Кр, Ki and Kd of the controller are selected in accordance with the Ziegler-Nichols method, which is intended for the optimal tuning of the PID controllers. Fig. 6 presents the results of the simulation of the GD work before and after optimization.

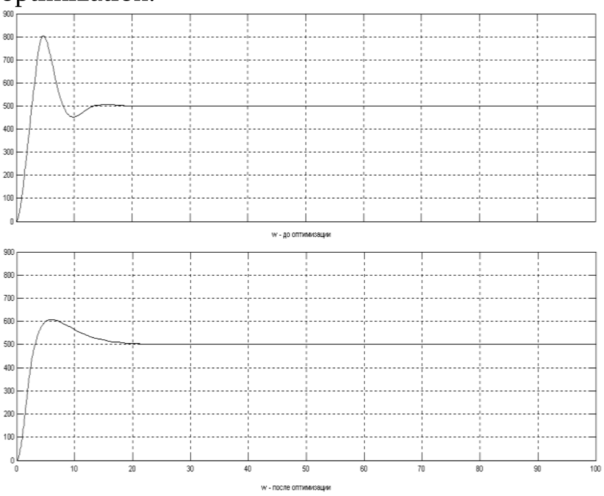

Fig. 6. Transients in the system before and after optimization of the controller parameters

Fig. 7 shows the result of optimizing the PID controller coefficients.

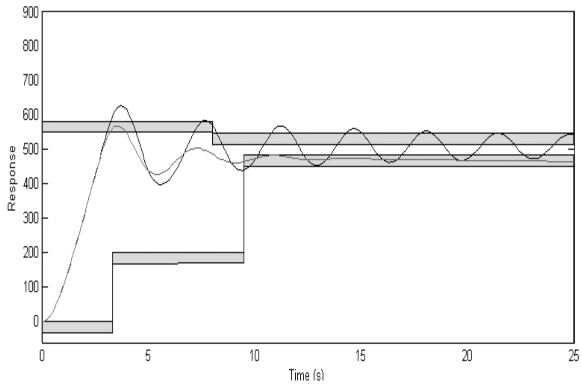

Fig. 7. Result of controller parametric optimization

The result of the work to optimize the PID controller coefficients is to derive the dependence of these coefficients on the power of the load on the engine shaft. The disadvantage of the proposed approach is the need for preliminary tests to obtain the values of the coefficients, which are later used to correct the PID controller. The values of these coefficients are dependent on the parameters of the model, which in practice is explained by the characteristic features of a single gas engine.

4 Conclusion

As a result of the study, a clarified model of a gas-diesel device was obtained. The problem of parametric optimization of the gas-diesel device speed controller has been solved, which has made it possible to minimize the value of overcontrolling and the duration of the transition process in the dynamic modes of operation of the power unit.

It was established that a gas engine with an air valve has significant non-linearities that should be considered when choosing the parameters of the controller. The linearization within certain limits of some non-linearities of the system allows us to avoid complex and resource consuming calculations in modeling.

Given that the nonlinearities indicated in the article affect not only the contour gain ratio, but also time constants that have dominant effect on the stability of the system as a whole, it is necessary to rebuild all the PID controller coefficients with the load power changes. At the same time, the nature of the change in the PID regulator coefficients should depend on the choice of criteria for optimizing the operation of a gas-diesel device in dynamic modes.

References:

[1] Campbell St. L., Chancelier J.-P., Nikoukhah R., Modeling and Simulation in Scilab/Scicos with ScicosLab 4.4, New York: Springer, 2006.

[2] Lukutin B.V., Shandarova E.B., "Ways of decrease in fuel consumption of diesel power station / B.V. Lukutin," Modern problems of science and education, Academy of natural science, No. 2, pp. 1-4, 2013.

[3] Tsekouras G. J., Hatzilau I. K., Prousalidis J. M., "A new pattern recognition methodology for classification of load profiles for ships electric consumers," Journal of Marine Engineering and Technology, No. 14, pp. 45-58, 2014.

[4] Mahmoud Mohammad Salem Al-suod, Ushkarenko Alexander O., Dorogan Olga I., "Optimization of the structure of diesel-generator units of ship power system," International Journal of Advanced Computer Research (IJACR), Vol. 5, Issue 18. pp. 68-74., 2015.

[5] Waleed F. Faris, Hesham A. Rakha, Raed M. Kafafy, Moumen Idres, Salah Elmoselhy, "Diesel Engine Analytical Model," International Journal of Scientific & Engineering Research, Vol. 3, Issue 8, pp. 1-12, 2012.

[6] K. Bala Showry, A.V. Sita Rama Raju, "Simulation of Injection Angles on Combustion Performance Using Multiple Injection Strategy in HSDI Diesel Engine by CFD," Int. J. Engineering and Technology, Vol. 2, No. 4, pp. 234-239, 2010.

[7] Miedema S.A., Lu Z., "The Dynamic Behavior of a Diesel Engine," Proc. WEDA XXII Technical Conference & 34th Texas A&M Dredging Seminar, June 12-15, Denver, Colorado, USA.

[8] Ryabenkiy V., Ushkarenko A., Al-Suod Mahmud Mohammad, "Reduction of Frequency Oscillation of the Gas-diesel Generator Units," Proc. TCSET'2012 International Conference "Modern Problems of Radio Engineering, Telecommunications, and Computer Science, Lviv Polytechnic National University, pp. 447-448, 2012.