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SYSTEM OF LOAD DISTRIBUTION OF SHIP DIESEL GENERATORS BASED ON NEURAL NETWORKS

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СИСТЕМА РАСПРЕДЕЛЕНИЯ НАГРУЗКИ СУДОВЫХ ДИЗЕЛЬ-ГЕНЕРАТОРОВ НА ОСНОВЕ НЕЙРОННЫХ СЕТЕЙ

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Keywords

Ship diesel-generator set; ship power station; parallel work; load distribution; electric power; specific fuel consumption; fuel consumption; minimization of fuel consumption; steady mode; neural network; neural network control.

Abstract

The dependence of the specific fuel consumption of the ship diesel-generator set on the generated electric power and the power factor is given. An algorithm for load distribution between parallel marine diesel generator sets is given, taking into account the dependencies of the specific fuel consumption on the generated power and the power factor of each marine diesel generator set. The possibility of using neural networks to solve the problem of minimizing the specific fuel consumption for parallel operation of ship diesel-generator sets in the steady state mode is considered. A neural network model for reducing fuel consumption is proposed by distributing the total electric load of a ship power plant between diesel generators operating in parallel. Such a model, based on the database obtained in the training process, which is implemented by microprocessor controllers with the algorithms of searching for a combination of capacities inherent in them for each of the parallel running generator, at which the minimum flow is reached, independently determines how it is necessary to load the units operating in parallel, to achieve a minimization of fuel consumption; and periodically checks the correspondence between the estimated (calculated) and the actual fuel costs, which ensures the control of the technical condition of the mechanisms.

Ключевые слова

Судовой дизель-генераторный агрегат; судовая электростанция; параллельная работа; распределение нагрузки; электрическая мощность; удельный расход топлива; расход топлива; минимизация расхода топлива; установившейся режим; нейронная сеть; нейросетевое управление.

Аннотация

Приведена зависимость удельного расхода топлива судового дизель-генераторного агрегата от вырабатываемой электрической мощности и коэффициента мощности. Приведен алгоритм распределения нагрузки между параллельно работающими судовыми дизель-генераторными агрегатами с учетом зависимостей удельного расхода топлива от вырабатываемой мощности и коэффициента мощности каждого судового дизель-генераторного агрегата. Рассмотрена возможность использования нейронных сетей для решения задачи минимизации удельного расхода топлива при параллельной работе судовых дизель-генераторных агрегатов в установившемся режиме. Предложена нейросетевая модель снижения расхода топлива путем распределения общей электрической нагрузки судовой электростанции между дизель-генераторами, работающими параллельно. Такая модель на основании базы данных, полученных в процессе обучения, которое реализуется микропроцессорными контроллерами с заложенными в них алгоритмами поиска комбинации мощностей, приходящихся на каждый из параллельно работающий генератор, при которых достигнут минимальный расход, самостоятельно определяет, как необходимо нагружать агрегаты, работающие в параллель, чтобы достичь минимизации расхода топлива; а также периодически проверяет соответствие между предполагаемым (рассчитанным) и фактическим расходами топлива, что обеспечивает контроль технического состояния механизмов.

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Introduction

To date, in the field of transport and operation of energy systems, the question of minimizing fuel consumption remains topical. The study of issues related to the reduction of fuel consumption during the operation of diesel power plants is given in [1], [2], [3], [4].

For example, in the field of water transport, ship power plants, equipped with two or more marine diesel generator sets (SDG) units operating in parallel, are set forth by the classification societies (Russian Maritime Register of Shipping (RMRS)) classification and construction of ships [Part XI «Electrical Equipment» ND №2-020101-104, 2018. - 138 p.]. According to these requirements, in parallel operation of alternators in the range from 20 to 100% of the total load, its distribution to each generator should occur in proportion to their capacities and should not differ by more than 15% from the calculated load of the larger generator or 25% from the calculated load of the generator under consideration, whichever is less [5]. Currently, the total load is distributed between parallel-working SDG-units according to these requirements, but without taking into account the dependence of the specific fuel consumption (URT) on the generated electric power of each SDG-unit.

Main part

The minimum fuel consumption of a single diesel generator set when the load changes is determined by its dependence of specific fuel consumption q on the generator electric power output Pg, originally obtained from factory tests of a serviceable diesel generator using standard fuel and given in the data sheet of each SDG-unit. The minimum specific fuel consumption usually corresponds to the load range of 75–85% of the nominal electric power of the unit, and going beyond this range results in excessive fuel consumption. In the passport data is usually given the dependence of the specific fuel consumption only from the active electric load diesel generator unit, that is, when the power factor is equal to unit cosφ = 1. With a decrease in cosφ of the load, the specific fuel consumption increases.

In the process of long-term operation of SDG-units, there is a change in the dependence of the specific fuel consumption on the output power of the diesel (generator), that is, an increase in the specific fuel consumption and a shift in the range of loads corresponding to the minimum specific fuel consumption (SFC). In addition, even for single-type diesel generator sets of the same rated power and assembly before commissioning (or after overhaul), the dependence of the SFC on the relative power of the generator

$$\overline{P} = \frac{P}{P}$$

and the power factor cosφ, as a rule, do not coincide (PGN is the rated power generator power), and for SDG-units of unequal power, the difference in the dependences may be more significant. In fig. 1 shows the URT dependencies on power for two ship SDG units with brushless synchronous generators of the same assembly and the same power (PGN = 750 kW, Un = 440 V) with a power factor of cosφ = 1, built according to factory test data before commissioning. Questions on the dependence of fuel consumption on the load, the nature of the load, period of operation, quality of electricity, etc., are displayed in [6], [7], [8], [9], [10].

For generators operating in parallel, the distribution of the total load of the shipboard power plant in strict proportion to their nominal capacities may not be effective in terms of minimizing specific fuel consumption due to the uneven nature of the SFC change from electric power and power factor; and during long-term operation of SDG-units, these dependences change, and the difference between them can increase significantly.

Rules for the classification and construction of ships RMRS deviations in load distribution between parallel generators are allowed in proportion to their capacities, therefore, taking into account the difference in SFC dependencies on power, the load between generators can be divided taking into account these dependencies so that the total specific fuel consumption is less than if the load was shared strictly proportionally.

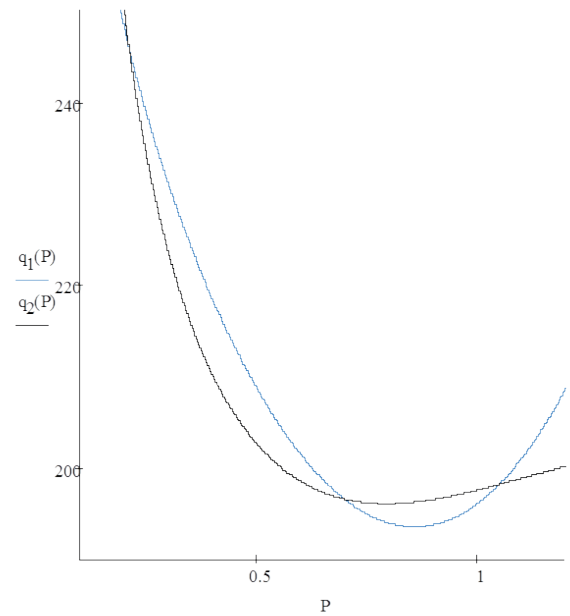

Fig. 1. The dependence of the specific fuel consumption of SDG-unit from the power load

Рис. 1 Зависимость удельного расхода топлива ДГА от мощности нагрузки

To do this, it is necessary to know the regression dependence of the specific fuel consumption q (PG) on the value of the electric power PG and power factor cosφ for each SDG-unit operating in parallel, and taking into account their technical condition at the considered time point.

In accordance with the methodology described in [11], [12], the dependence of the specific fuel consumption of the SDG unit on the generator power and cosφ can be represented as follows:

$$q(P_Г) = \frac{k_1}{\cos^4\varphi}\cdot P_Г{}^3 + \frac{k_2}{\cos^2\varphi}\cdot P_Г{}^2 + (k_5 + \frac{k_6}{\cos^2\varphi})\cdot P_Г + k_3 + \frac{k_4}{P_Г}$$

here $q(P_G) = \frac{10^3 \cdot Q}{P_G}$ (gr/kW·h) – specific fuel consumption of SDG-unit; P_G (kW) – synchronous generator power; Q (kg/h) – fuel consumption; $\cos\varphi$ – power factor of load; $k_1 \div k_6$ – constant coefficients depending on the technical state of SDG-unit: $k_1 = \frac{10^{15}}{9 \cdot U^4} \cdot K^2_{Г} \cdot K_{Д2}$ (gr/kW^4·h),

$k_2 = \frac{2 \cdot 10^9}{3 \cdot U^2} \cdot K_{Г} \cdot K_{Д2}$ (gr/kW^3·h), $k_3 = 10^3 \cdot K_{Д1}$,

(gr/kW·h), $k_4 = 10^3 \cdot Q_{const}$, (gr/ h), $k_5 = 10^3 \cdot K_{Д2}$,

(gr/kW^2·h), $k_6 = \frac{10^9 \cdot K_{Г} \cdot K_{Д1}}{3 \cdot U^2}$, (gr/kW^2·h), $K_{Г}$ (kW/A^2), $K_{д1}$ (kg/kW·h), $K_{д2}$ (kg/kW^2·h); Q (kg/h) – fuel consumption; U (V) – generator voltage; Q_{const} (kg/h) – the constant component of fuel consumption corresponding to the fuel consumption at idle SDG-unit.

To search for such a combination of electrical power, falling on each of the parallel working SDG-units, in which the total specific fuel consumption would be minimal than with a strictly proportional load distribution between the SDG-units, the problem of choosing the power of parallel operating SDG-units (PG_1 and PG_2) satisfying the conditions:

$$P = P_{Г1} + P_{Г2} \quad (2)$$

$$q(P) = [q(P_{Г1}) + q(P_{Г2})] \to \min \quad (3)$$

The enlarged scheme of the algorithm for solving this problem is shown in Fig. 2 — a continuous measurement of the power and cosφ of the shipboard power plant is made, the measurement results and the regression dependencies (1) for each SDG unit are entered into a computer model in which, based on the analysis, load distributions between parallel SDG-units for a given power of a marine power plant and cosφ is determined by the load distribution with the minimum total specific fuel consumption.

According to the studies carried out in [11], [12], the coefficients K_G, K_{D1}, K_{D2}, Q_{const} in expression (1) are determined on the basis of periodic tests of the SDG-unit at different loads. When the voltage U, the frequency f and the power factor cosφ is constant, the coefficients K_G, K_{D1}, K_{D2}, Qconst determine the dependence q (P_G). It is important to note that the values of the coefficients K_G, K_{D1}, K_{D2}, Qconst during operation will change due to changes in the technical state of the SDG-unit, and therefore periodic correction of these coefficients is necessary, for example, during maintenance or after repair.

According to known values K_G, K_{D1}, K_{D2}, Q_{const} for each parallel SDG-unit and the value of the total electric power P in the steady state, the task of finding a combination of power (P_{G1} and P_{G2}) for parallel SDG-units, corresponding to the minimum total specific consumption fuel can be solved using a convergent cognitive-informational complex based on neural networks for the ship's power station, equipped with two or more SDG-units operating in parallel. In addition, using such a complex, it is possible to predict the above factors using the database of SDG aggregates obtained during operation, which will allow to correct the dependence q (P) for each SDG-unit The reliability of the q (P) dependence is important for increasing the accuracy of minimizing the total SFC.

The use of neural network modeling seems to be the most promising for modeling input-output ratios of parameters in ship power systems. Implementing a neural network providing the minimum total fuel consumption at a given value of the total power of the ship power station in the steady state is possible with a database of previous power measurements of the parallel operating SDG-units P_{G1} and P_{G2} corresponding to the minimum total URT, with known electrical power power plants P∑, which can be performed by modern microprocessor tools developed by Russian and foreign companies for maritime fleet. Such a database can be formed by a neural network for a certain period of time in use to solve the problem of minimizing the fuel consumption of the microprocessor controller, in which the above-mentioned algorithm is laid (Fig. 2). After a set of sufficient numbers (combinations - P_{Σ}; P_{G1}; P_{G2}; qmin), that is, after the training stage is completed, the neural network itself determines how it is necessary to load the SDG-units operating in parallel to achieve minimization of SFC.

As noted above, the coefficients that determine the dependence q (P) for SDG-units depend on the technical state of the mechanisms and change with time.

The neural network forms a database for fixed values of coefficients (K_G, K_{D1}, K_{D2}, Q_{const}) for each SDG-unit, received at some moment of time, and does not take into account their change over time, which is its disadvantage. To eliminate this drawback, it is proposed to compare the results calculated by the neural network (minimum total SFC) and the actual values of the SFC with a given periodicity, and if these values diverge more than the set limit, generate a signal for the correction of coefficients (K_G, K_{D1}, K_{D2}, Q_{const}), conduct retraining of the neural network with adequately new coefficient values (K_G, K_{D1}, K_{D2}, Q_{const}). Thus, with the help of such a model of a cognitive-information complex based on a neural network, the technical state of SDG aggregates can also be monitored.

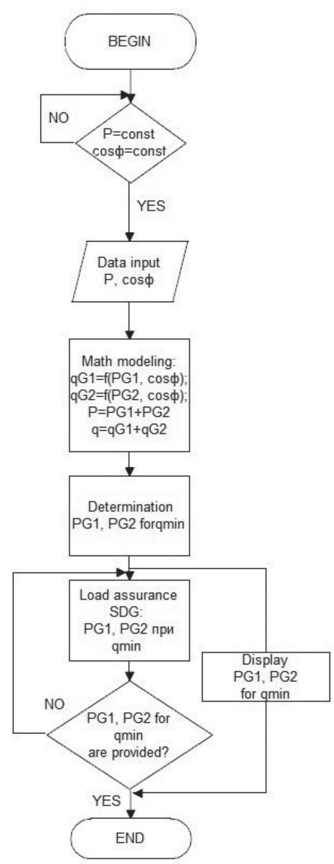

Fig. 2. A block diagram of the load distribution algorithm between parallel operating ship diesel generator sets

Рис.2. Блок-схема алгоритма распределения нагрузки между параллельно работающими судовыми дизель-генераторными агрегатами

In fig. 3 shows a neural network model for minimizing fuel consumption.

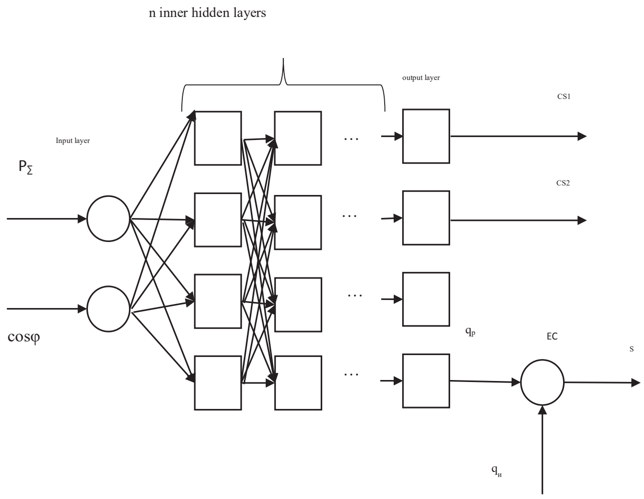

Fig. 3. Neural network model to minimize fuel consumption
Рис. 3. Нейросетевая модель минимизации расхода топлива

The model consists of the input layer, the n-th number of inner hidden layers, the output layer, the comparison element EC.
In the steady state mode, the signals from the sensors come to the model input - the total electrical power of the shipboard power station P and the value of the power factor cosφ. Based on the generated database, the trained neural network model sets the values of P_{G1} and P_{G2} at which the total specific fuel consumption q_Σ is minimal and generates signals CS1 and CS2 - control signals for setting the fuel consumption corresponding to the minimum fuel consumption for a given load. Control signals CS1 and CS2 change the position of the fuel rail SDG-units. The minimum SFC qa calculated by the model is compared with the actually measured SFC qfact value and in the EC comparison unit: when the difference between the calculated and measured SFC values exceeds the set limit, a significant change is made in the technical state of the SDG-units “S” and the need to retrain the neural network.
In the works [13], [14] it is shown how the reduction of fuel consumption of diesel generator sets in systems with variable speed is carried out.

Conclusion

Automatic control using neural networks of one process or another is a promising direction in the development of modern technology; and is currently being actively tested and used in engineering [15]. Most of the difficulties encountered in the operation of marine diesel generators are associated with a large number of controlled parameters and the inability to control their change in full. In such conditions, neural network control is effective for solving certain technical problems. So in this work, the neural network model, previously trained, provides minimal fuel consumption and monitors changes in the technical state of SDG-units even in the presence of interference in the input data or in conditions of lack of information.
Also, issues related to optimization, including the use of intelligent systems, the operation of autonomous diesel power plants for fuel economy, are discussed in [16] - [20].

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