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Optimization of the structure of diesel-generator units of ship power system

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Abstract

The study proposes the algorithm for selecting the optimal values of rated power generating units, based on the statistical processing of information about the daily workings of the energy generators accumulated software top-level automated control system (ACS) power plant. The calculated nominal capacity can be used to select the diesel-generator units when upgrading the ship power station.

Keywords

diesel-generator, ship power station, state chart, simulation, optimum unit commitment.

1. Introduction

One of the important indicators of diesel power plants is the cost, which is the ratio of energy produced to the fuel consumption per hour of operation. Reducing fuel consumption will improve the energy efficiency of autonomous diesel power. The main reasons for the increase in fuel consumption are low temperature and loading inefficient generating units (DGU) [1]. In [2-4] the ways to reduce the fuel consumption of existing shipboard electric power plant (SPP) by introducing a buffer storage and transfer of power diesel generators at variable speed depending on the electrical load. However, these methods require a radical reorganization of the structure and modes of operation of the plant. This raises the problem of simulation of the power plant, as a result of which must be obtained diagrams of consumers of electricity and power delivered diesel generators on the total load, in the form of records in the database.

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Modeling of ship power electrical loads are dedicated papers [2, 3, 5], but there the result of the simulation is the total power consumption schedule SPP used to determine the composition and powers of the projected power generating units. In order to optimize the composition of generating units there must be received the load graphics for each of the units.

2. The main material

The instantaneous value of the load power is a random variable and is determined by the composition of the instantaneous values of loads of individual consumers.

Schedule power consumption of each device is formed by three components: the power level p, t duration of the work and the duration of the pause τ, which may be permanent or randomly distributed in time [5]. In [5, 6] adopted the following algorithm for calculating loads, designed as a package of applications: modeling power level, duration of work and pauses for each user; imposition of components on the load curve of the consumer; formation of the schedule based on the total load of all simulated loads of consumers. The above algorithm cannot account for correlations between modes consumers. The paper proposes the use of the automatic approach for scheduling work and loads of consumers generating units, which will formalize the problem of modeling and taking into account the relationship between consumers.

For correct sizing the generator power is necessary in the first place on the basis of information accumulated over a certain period of operation of the automated control system, perform the calculation of peak load power:

$$P_n = \max_{j \in [1;\, m \cdot n]} \sum_{i=1}^{g} P_j^i \,, \quad (1)$$

where P_n – the peak load power plants,

P_j^i – power supplied by the DGU in P_j^i point in time,

g – the number of diesel generators,

m – number of full days, during which the accumulation of information,

n – the number of records per day.

The maximum load of the total power of all diesel generators, is calculated from the peak power with a small (up to 20%) margin:

$$P_{\max} = k_{fill} \cdot P_n \,, \quad (2)$$

where $P_{\max}$ – the maximum load power,

P_n – peak load power plants,

k_{fill} – safety factor in fractions of a unit.

Since the optimal will be the combination of power generating units at which the average deviation from the nominal load is minimal and maximal duration of works DGU, the next step is to do the following.

1) Formation of the average daily power generation all the diesel generators:

$$\overline{P_i} = \frac{\sum_{j=1}^{m} \sum_{k=1}^{g} P_{j,\,i}^{k}}{m} \,, \quad (3)$$

for $i \in [1, n]$, where g - the number of diesel generators,

m – number of full days, during which the accumulation of information,

$\overline{P_i}$ – The average value of the power generation per day i,

$P_{j,i}^k$ – Power supplied by the DGU in P^k at j time for the i day.

2) The formation of the many possible combinations of nominal capacity of DGU. The initial data for their calculation are the minimum power diesel generator step of varying capacity and power which must provide all the diesel generators. The number of possible combinations is calculated as:

$$c = \sum_{i=1}^{c_{\max}} c_i \,, \quad (4)$$

where

$$c_{max} = \frac{P_{max} - g \cdot P_{min}^1}{\Delta P^1} + 1 \,,$$

and

$$c_i = c_{max} - (i - 1).$$

For each c_i – the amount of combinations of tuples power ratings are calculated as DGU (for example, three units):

$$\left\langle P_k^1, P_k^2, P_k^3 \right\rangle, \quad (5)$$

where

$$\begin{aligned} P_k^1 &= P_{i,\,j}^1 = P_{min}^1 + i \cdot \Delta P^1, \\ P_k^2 &= P_{i,\,j}^2 = P_{min}^1 + j \cdot \Delta P^1, \\ P_k^3 &= P_{i,\,j}^3 = P_{max} - P_k^1 - P_k^2, \end{aligned} \quad (6)$$

For each $j \in [1; c_i]$, $P_{\max}$ – the maximum load power.

3) The calculation of the power delivered to the total load for each diesel generator set from each tuple. The calculation is performed on the basis of the average daily power generation and the following conditions are met: the first the generator rated power equal to the first value tuple is connected to the main switchboard bus bars; each successive generator switched to the parallel operation of the previous load provided by more than 80%; when loading at least 20% of at least one of the generators of the last paralleling DGU is disabled; the load is distributed strictly in proportion to the nominal power of the generator.

4) Calculation of the average deviation of the loaded diesel generators of the nominal load (0.75):

$$\overline{\Delta k_k} = \frac{1}{g \cdot n} \cdot \sum_{i=1}^{g} \sum_{j=1}^{n} \left| \frac{P_j^i}{P_{nom}^i} - 0{,}75 \right| \quad (7)$$

where P_j^i – power supplied by the DGU in P_j^i point in time,

P_{nom}^i – rated power of the i-th generator,

g – the number of diesel generators,

n – the number of records per day,

and the average duration of all DGU:

$$\overline{t_k} = \frac{1}{g} \cdot \sum_{i=1}^{g} \underset{j \in [1;\, n]}{count} \left(P_j^i > 0 \right), \quad (8)$$

for each k-tuple order.

5) Selection of tuples, the average deviation downloaded for which the minimum, and then among

the candidates – that (those) for which the average duration of a maximum of DGU:

$$\max_{t_k} \min_{\Delta k_k} \left\langle \left\langle P_k^1, P_k^2 \ldots P_k^i \right\rangle, \overline{t_k}, \overline{\Delta k_k} \right\rangle, \quad (9)$$

where $\overline{t_k}$ – the average duration of the *k*-th DGU,

$\overline{\Delta k_k}$ – average absorption deviation of the *k*-th load of diesel generator from the nominal load.

The resulting tuple (tuples) will contain the values of rated capacity, where diesel generators will be used most effectively. For each type of vessels can be identified characteristic regimes governing diagram of the consumers. Furthermore, in most modes allocated cyclic time sequence and duration of stages – random variables which are statistically distributed in the time. For most types of vessels can be identified consumer groups, the characteristics of the distribution laws at work, pause and power level which depends on the phase of the cycle. For example, for fishing vessels characteristic modes are in port, maneuvering, the transition to fish move from the fishery, fishing and emergency modes. For each mode, a specific type of fishing vessels can be identified stages of the diurnal cycle. As an example, consider long line vessels fishing in the mode for which are characteristic stages of productions, drift and hauling. The duration of each stage random variables distributed according to a uniform law. On the stage of the cycle gear connected modes of electricity consumers, providing prey fish (winches, fishing mechanisms, search equipment), refining (mechanisms fishing shop and freezers) and storage (mechanisms refrigeration unit), □ in each of the characteristics of distribution laws of random values (power level, duration and pause) are different. As an individual consumer at any one time can be in one of two states (on or off), it is proposed to consider it as a state machine. Condition of transition between states is the completion of a random period of time, generated on the basis of the empirical form of the distribution and characteristics. In the form of a finite state machine can be seen daily cycle operation of the vessel: each step corresponds to one of the machine, while the length of stay in the state machine – a random variable distributed uniformly in the interval, the boundaries of which depend on the number of stages.

As a tool for simulation of consumers using State flow software environment MatLab. Established in its network of machines, described below, is used as an integral part of the model plant, and called on each step of the simulation (one step corresponds to 5 minutes. Real-time). Figure 1 shows a diagram of State flow-finite automaton S, simulating shift stages of the technological cycle of the vessel: parking, staging, drift and selection of tiers (state C0 to C4, respectively).

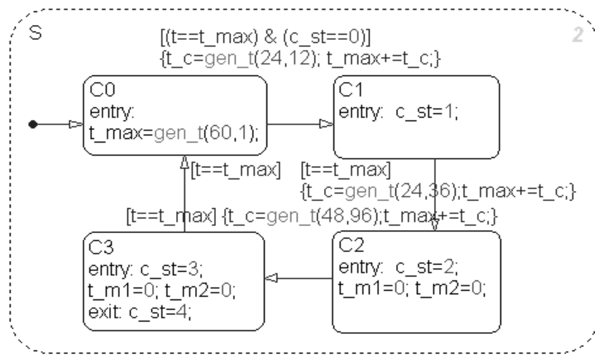
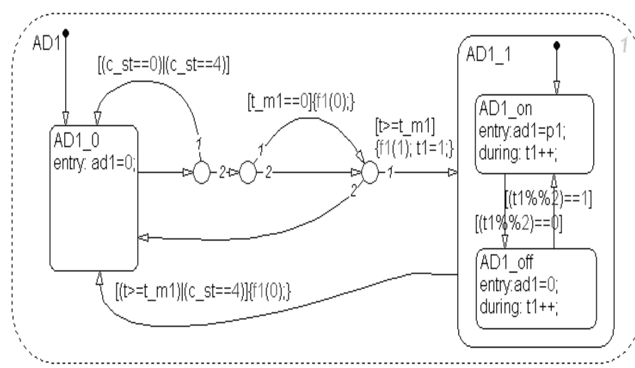


Figure 1: The state machine, which simulates the shift stages of the technological cycle of the vessel

Change of the diurnal cycle stages of the vessel and the work of each of the electricity consumers are parallel processes, so when you create a super state used in parallel decomposition, each of which implements the appropriate machine.



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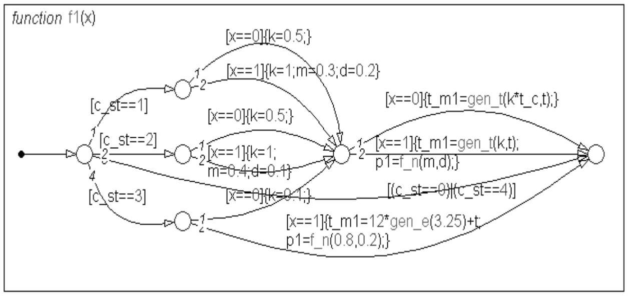

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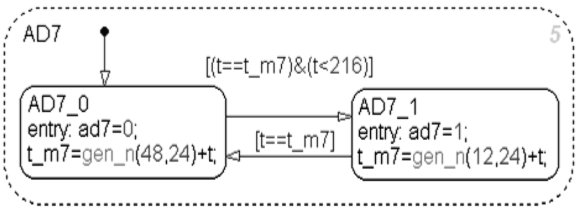
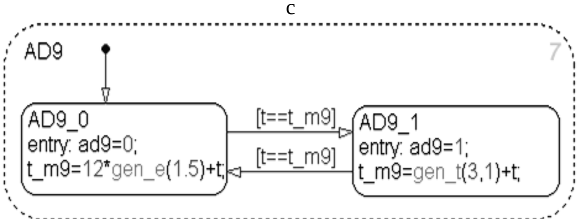


c

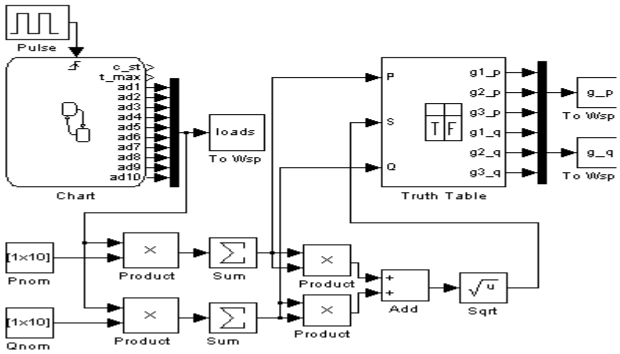


d

Figure 2: Finite state machines that simulate the work of electricity consumers: a – depending on the phase of the circadian cycle of the consumer; b – function used to generate random variables; c, d – consumers, whose work does not depend on the technological phase of the vessel

Fig. 2a, is shows a graph diagram machine AD1, simulating the operation which depends on the phase of the circadian cycle vessel consumer AD1. Of AD1_0 off state corresponds to an object of AD1_1 – included. Powered consumer works in intermittent mode (this mode is typical for lifting mechanisms) with a period of 10 minutes. and duration of the motor 5 min., so the state AD1_1 divided into two sub-states – enable or disable during operation (AD1_on and AD1_off respectively). Mode of operation of the consumer depends on the stage of the technological cycle of the ship. At the stage of parking (C0 state automaton S) Machine AD1 is in AD1_0 (consumer off). In the transition to state automaton S C1, which corresponds to the transition in the vessel line setting mode, generates a random number, which corresponds to the time included in the job waiting consumer.

Upon completion of the generated amount of time there is a transition to a state machine AD1 AD1_1, accompanied by the generation length of stay, and the level of power consumed by a mechanism in relative units. In the state AD1_1 there is a cyclic transition from state to state AD1_on AD1_off and back with a period of 2 cycles simulating Intermittent operation of the mechanism. The coincidence of the residence time of the machine in the state with the generated AD1_1 duration triggers a transition to a state machine AD1_0, then repeat the actions described. In modes vessel "drift" and "hauled" (C2 and C3 state automaton S) modeling of consumer AD1 is similar; the difference exists only in the types of distribution laws of power level, service intervals and pauses, and their characteristics. To minimize bulkiness model generation of random variables is implemented as a graphical function f1 (e.g. Fig. 2b) with parameters – direction of the transition (from AD1_0 in AD1_1 or reverse) and the number of the cycle of the ship; return values – time to reverse transition to the current state and the level of power consumed by the engine. The second group of customers include consumers, mode of operation does not depend on the technological phase of the vessel: mechanisms of systems supporting the work of the main engine and propulsion, ship systems and storage of cargo (e.g. Fig. 2d). Mode of operation of consumers in this group may depend on the time of day (e.g. Fig. 2c). Similarly machines AD1, AD7 and AD9 designed machines that mimic the work of the most powerful and running periodically or occasionally ship electricity consumers; power consumption of other devices is taken into account in the form of a constant component. A set of parallel machines combined form State flow-model of marine consumers. Input event for the model is the edge of the clock signal, initiating check the conditions of transition and change in the states of the automata. Output signals – power level consumed by devices in a fraction of the rated power (in this paper we consider 9 consumers with variable load and one generalized, constant). For diagrams of generating units State flow-model is used as part of Simulink-model shown in Fig. 3a. The output signals of the model works electricity consumers are combined into a vector, and then to go to the absolute power unit runs its element wise multiplication by a vector of values of the nominal active (Pnom) and reactive (Qnom) power consumers.



a

Condition Table

	Description	Condition	D1	D2	D3	D4
1	0 < S < 100	S < 100	T	-	-	F
2	100 <= S <= 350	S >= 100	-	T	-	F
3	350 < S	S > 350	-	F	T	F
		Actions: Specify a row from the Action Table	1	2	3	4

Action Table

#	Description	Action

1		g1_p = P; g1_q = Q;
		g2_p = 0; g2_q = 0;
		g3_p = 0; g3_q = 0;

2		g1_p = P*2/7; g1_q = Q*2/7;
		g2_p = P*5/7; g2_q = Q*5/7;
		g3_p = 0; g3_q = 0;

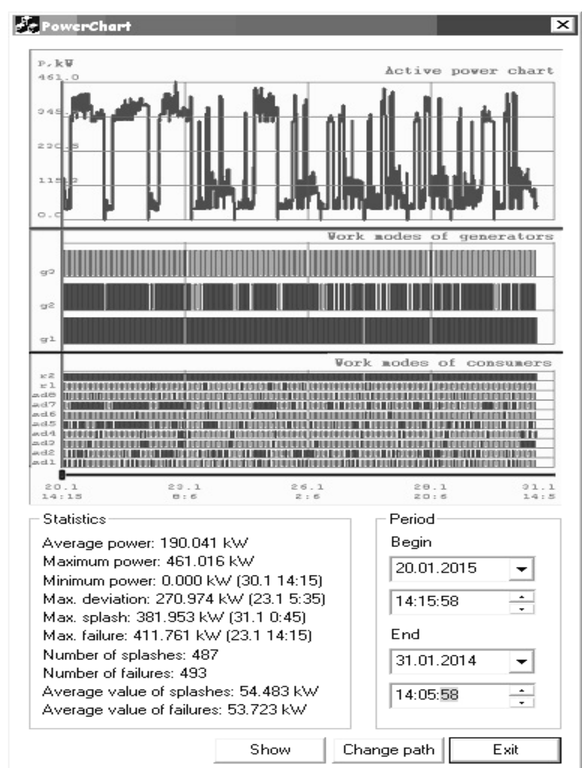
3		g1_p = P*2/10; g1_q = Q*2/10;
		g2_p = P/2; g2_q = Q/2;
		g3_p = P*3/10; g3_q = Q*3/10;

4	For first modeling step	g1_p = 0; g1_q = 0;
		g2_p = 0; g2_q = 0;
		g3_p = 0; g3_q = 0;

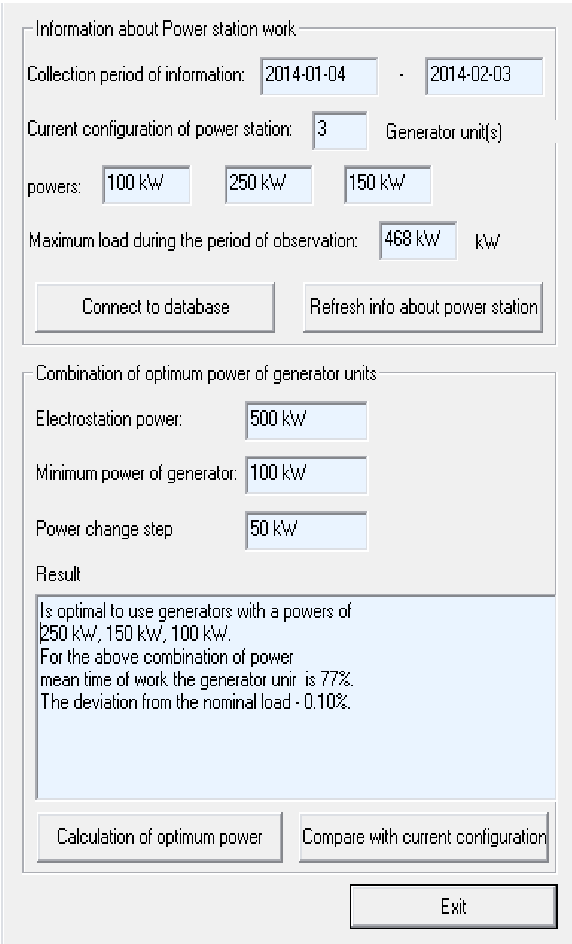
b

Figure 3: Model of power plant: a – a block diagram; b – the contents of the block «Truth Table»

Based on the resulting vectors the total power consumption is calculated. Calculation of the power supplied to each generating unit (GU) in the load is performed using block select an option (Condition Table in the environment Simulink; e.g. Fig. 3b). This paper considers the electric power plant, which as a source of electricity used by three hectares with different power ratings (100 kW, 250 kW and 150 kW). The input Truth Table enters the total of the power consumption; the decision to include parallel operation GU is taken on the basis of the analysis of the values of full power. If the latter is less than 100 kVA (0.8 nominal power of the first GU), is only one GU; if located within 100 – 350 kVA works two GU and if more than 350 kVA – all three GU. In parallel operation of several GU simulated distribution of active and reactive loads in proportion to the nominal capacity of GU. Truth Table output parameters are the values of active and reactive power generated by each of the three GU. For the record obtained by modeling diagram of consumers and generators in the database matrix of values and quantities consumed levels generated power is transmitted to the workspace Matlab. We use a DBMS PostgreSQL, to communicate with the driver which uses PostgreSQL JDBC. On the basis of data from the Matlab workspace generated SQL-queries to fill tables (tables graphs and tables load modes GU); Connect to the database and execute queries implemented in Java using the classes provided by the driver PostgreSQL JDBC. For convenience for working with the model there was created Matlab-function, where an interval simulation of power (the number of full days) is passed as an argument. Function downloads the driver, connects to the database and, if necessary, creates tables, simulation of power and filling tables and charts load modes generating units. The resulting simulation of the month (30 days) of the power plant data were used to test software tools for statistical analysis of process power oscillations (e.g. Fig. 4a) and to optimize the composition of the generating units (e.g. Fig. 4b).



a



b

Figure 4: Interface routines: a – a statistical analysis of process power oscillations; b – finding the optimal capacity of DGU

Optimal load diesel generator load is considered to be close to 75% of the face: when the engine is less stress increases fuel consumption and shows the effect of carbonation caused by congestion in the cylinders of the products of incomplete combustion, which negatively affects the life of the engine; Loading the generator set more than 75% also leads to a significant reduction in efficiency [3]. An indirect indicator of the effectiveness of the use of the unit is the duration of his work.

3. Conclusion and Future Work

In the paper, there were developed algorithms for calculating the statistical characteristics of the power fluctuations and finding the optimal combination of rated power diesel generators, the use of which for the processing of information accumulated in the process of SPP, will determine the need for measures to improve the stability of the parameters of electric power in the system and to improve the efficiency of the SPP at the conduct of its reconfiguration. Algorithm for selecting optimal power diesel generators, powered paper is based on two criteria: the minimization of fuel consumption and maximize the time congestion engines. Also, the basic condition is a constant number of generators of electricity during the modernization of the power plant.

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