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Monitoring and Automatic Control for Ship Power Plants Based Logical Algorithms

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Abstract

Controlling power station systems with diesel engines is vital issue. Algorithms of microprocessors are developed to be used in the control unit of this type of power station systems. Such Algorithms are built in a logic form, and then the control functions are derived using logic functions. Analyzing the contents of the received logic signals allows us to overcome structural redundancy of the systems. Monitor the network parameter is very important to protect the devices used in the power station systems. In this paper automated controller is developed using microprocessor algorithms to view and control the parameters of the system devices such as generator, synchronizers, and load sharers on-line, this will help in improving the system to be fast, reliable and more accurate. This paper proposes an implementation of a subsequent optimization for structural and algorithmic blocks of microprocessor systems automation of ship power plants.

Keywords

Power System, Control System, Monitoring, Logical Algorithms.

1. Introduction

According to the rules of classification and construction of marine vessels, [1] automation systems of ship power plants (SPP) must satisfy some requirements such as: remotely control of both starting and stopping of the generator drivers from the central processor unit (CPU), as well as synchronization, connectivity and load sharing between parallel working generator units of the CPU. For each motor drive, a speed controller, which has characteristics corresponding to the requirements of the factory, protection, and controlling the parameters are required. Each alternator must have a separate and independent automatic voltage regulation. A well design generator for parallel operation to protect against overload, short-circuit (overcurrent), reverse power, under voltage and field loss should be provided. Not only that, the operating power of alternators with maximum permissible load is required to be capable of automatic starting-up of additional generating unit with the subsequent synchronization connection to the bus bars of the main switch board (MSB) and load distribution. Monitor the parameters of ship power such as voltage, frequency, current, and resistance insulation for ship network load current, and loaned a total load capacity – for the generating units.

The modern approach to design the automated control systems (ACS) is to use hierarchical management system architecture. Installing ACS in ship power plants can be divided into three vertical subordinate levels (listed in order from bottom to top) as:

1) Local control motors and generators, which include automatic controls of engine speed and driving voltage generator. This required implementation algorithms to start and stop the engine in accordance with their factory instructions and tools to ensure the most high speed protection of the generator.
2) Automation tools that are essential for interoperability powertrains and optimize their use by correcting give and electricity consumed by them that are made by sending commands via the digital signals corresponding to local control systems.

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3) Computerized control system, so the data exchange can be transferred with automation midrange, which allows remote monitoring and control of electric power plant.

SPP generally consisting of several independent sections, in which the total load is several Diesel Generating Units (DGU). To ensure the above functions, ACS SPP on the second level of the hierarchy management system must have the following hardware automation: parameters monitoring system for ship network (one for each section), generator parameters monitoring system (for each diesel generator); protection device generators reverse power, loss of excitation, overcurrent and power, the minimum voltage and frequency (for each DGU); control device start/stop diesel generator to prevent overload/under load working DGU (one per section); synchronization system of the generator set with tires MSB (for each generator that is not the main section); distribution system resistive load between parallel working DGU (one for each section); reactive load distribution system operating in parallel between DGU (one for each section); expansion modules or programmable logic controllers to control the circuit-breaker (the number depends on the number of digital I/O devices and the number of loads that need to be remotely switched). The algorithms can be implemented on an 8-bit and 32-bit microcontrollers with RISC-architecture, such as the firm Atmel ATMega128, AT91SAM7S256 and others.

2. Logical Model of Ship Power Station

Table 1: Important Symbols Definitions

Symbol	Description
y0	the initial state
y1.1 - y1.3	are measurements of the ship's mains: RMS voltage, frequency and instantaneous voltage, respectively.
y2	is communication with upper level (here and after will be used the same notation).
y1.5-y1.10	measurements of the electricity generated by diesel generator: instantaneous voltage, instantaneous current, RMS voltage, RMS current, values, power factor and frequency, respectively.
x1	the condition "the breaker open"
z2.1	calculation of active power
x2.1	condition "power consumption exceeds the limit P≤-(0.08...0.12)Prat"
y3.1	generating the signal to the relay, disconnecting the generator breaker.
z2.2	reactive power calculation
x2.2	reactive power calculation; x2.2 – the condition "power consumption exceeds the limit Q≤-(0,08...0,12)Qrat"
x2.3	condition "current generator exceeds the limit I≤-(1...1,2)Inom"
y3.2	generating the signal to relay signals the operator overload fault.
x2.4	condition "Power supplied by the generator to the network exceeds the limit P≥(1...1,2)Prat"
x2.5	condition "generator voltage below the limit U≤0,3Uref"
x2.6	the condition "current frequency generator below the limit f≤0,95fnom"
x3	condition "check the status of generator circuit breakers all DGU";
x4.1 , x4.2	conditions "must include (x4.1) or disable (x4.2) additional DGU"
y3.3 , y3.4	signal generation circuit for the relay, signaling the operator to turn on (y3.3) or turn off (y3.4) additional generator
U1, U2, f1, f2	valid values of voltages, frequencies and angles of the vectors of mains voltages and plug the generator, respectively
x4	condition "received command initiates the synchronization process"
z2.3	payment differences voltage and frequency, and plug the generator
x5-x6	synchronization conditions (10)–(12)
y3.5	signal conditioning circuit on the generator circuit breaker
y3.6 , y3.7	formation correction signal generator excitation frequency and speed of the diesel engine,

	respectively.
x8.1	condition "given DGU network active power exceeds the set value".
x8.2	condition "give DGU network reactive power exceeds the set value".

To prevent hardware redundancy automation systems must have a means of analysis of the structural schemes [2, 3]. The work proposed for this purpose consideration microprocessor systems automation SPP in the form of control machines. Then, if for each system to allocate a set of operations, where each element will determine not only the algorithmic block action, but also the associated complex hardware to describe the functioning of the control automaton can use the language of logic algorithms, which, according to [4, 5], allow to optimize the structure of the individual and the totality of control machines. Last-level microprocessor systems will lead to their unification to eliminate hardware redundancy and rationalization of resource use microprocessors [6].

Monitoring system parameters of ship network serves for remote control of the current and the instantaneous values of voltage and frequency shipboard network; averaging time for the measurements of the current, voltage, and frequency is 120 sec. The system can be represented by the following logic:

$$y_0 \downarrow^1 \left[y_{1.1}\ y_{1.2}\ y_{1.3}\ y_2 \uparrow^1 \right]^{T=120s} \tag{1}$$

Logical diagram determines the order of operation depending on the value of its constituent logical conditions. First the leftmost operator scheme is executed. After that is determined which operator scheme should be carried out as next. If it was illogical operator, then it must be done for the element which is located immediately to the right or the one indicated by an arrow. If the latter was the logical condition, then there are two possibilities. If the condition is satisfied, then the item should work, standing on the right. If it is violated, the operator which is pointed by the arrow that starts after this condition has to work.

For example, in the abstract of, in Formula 1, a pair of up and down arrows marked with superscript 1 indicates that after completion of the measurement parameters ship network [y1.1-y1.3, y2] the transition goes (up arrow with index 1) to the initial state before measurement (down arrow with the index 1), ie, this logic diagram describes the cyclic operation of measuring the parameters of the ship's network.

System requirements for monitoring parameters are DGU measurement and transmission for remote display of current and instant values of voltage and frequency, current, active and reactive power supplied by the generator set to the total load. Time averaging measurements is 120 sec.

$$y_0 \downarrow^1 \left[y_{1.5} - y_{1.10}\ y_2 \uparrow^1 \right]^{T=120s} \tag{2}$$

The device for protection of generator from reverse power should be included after connecting DGU for parallel operation with other power alternators and perform periodic continuous measurement of active power supplied by the generator to the total load. If a situation arises in which the DGU will consume active power from the network (the magnitude of 8-12% of the rated power of the generator), longer than a certain time (5-15 sec.) this device must disconnect the generator from the network by acting on the generator circuit breaker:

$$y_0 \downarrow^1 x_1 \uparrow^2 \omega \uparrow^1 \downarrow^2 \begin{bmatrix} y_{1.7}\ y_{1.8}\ y_{1.9} \\ z_{2.1} \\ x_{2.1} \uparrow^1 y_{3.1} \uparrow^1 \end{bmatrix}^{T=5-15\,s} \tag{3}$$

The device for protection of generator from loss of excitation is also included after connecting DGU parallel operation with the network and serves to isolate the generator from the network in the event of their consumption of reactive power (value of 8-12% of the generator reactive power Q_{rat}) for more than a certain period of time (5-15 sec.):

$$y_0 \downarrow^1 x_1 \uparrow^2 \omega \uparrow^1 \downarrow^2 \begin{bmatrix} y_{1.7}\ y_{1.8}\ y_{1.11} \\ z_{2.2} \\ x_{2.2} \uparrow^1 y_{3.1} \uparrow^1 \end{bmatrix}^{T=5-15\,s} \tag{4}$$

The device for protection of DGU against current overload is used to measure RMS current generator and the output relay closes when the current exceeds the threshold value (100-120% of the nominal value I_{nom}) lasting longer than a certain period of time (5-10 sec.).

$$y_0 \downarrow^1 x_1 \uparrow^2 \omega \uparrow^1 \downarrow^2 \begin{bmatrix} y_{1.8} \\ x_{2.3} \uparrow^1 y_{3.2} \uparrow^1 \end{bmatrix}^{T=5-10\,s} \tag{5}$$

The task of the generator protection device overload capacity is alarm (relay output circuit) in excess of given DGU in the total active power load limit (100-120% of rated power P_{rat}) for more than a certain period of time (5-10 sec.):

$$y_0 \downarrow^1 x_1 \uparrow^2 \omega \uparrow^1 \downarrow^2 \begin{bmatrix} y_{1.7}\ y_{1.8}\ y_{1.9} \\ z_{2.1} \\ x_{2.4} \uparrow^1 y_{3.2} \uparrow^1 \end{bmatrix}^{T=5-10\,s} \tag{6}$$

The device for under voltage and the minimum frequency is designed to prevent reducing the effective value of the voltage is more than 70% and frequency by more than 5% from the nominal values for a certain time (5-30 sec.). By disconnecting from the network DGU:

$$y_0 \downarrow^1 x_1 \uparrow^2 \omega \uparrow^1 \downarrow^2 \begin{bmatrix} y_{1.7} \\ x_{2.5} \uparrow^1 y_{3.1} \uparrow^1 \end{bmatrix}^{T=5-30\,s} \tag{7}$$

$$y_0 \downarrow^1 x_1 \uparrow^2 \omega \uparrow^1 \downarrow^2 \begin{bmatrix} y_{1.10} \\ x_{2.6} \uparrow^1 y_{3.1} \uparrow^1 \end{bmatrix}^{T=5-30\,s} \tag{8}$$

For optimal use of DGU there was used the control device start/stop generators. Its task was to measure the active power delivered by all DGU common load, and to inform the operator or automatic control of additional generator at startup running generators for more than 80-90% (requires additional training to the parallel operation of the generator) or less than 10-20% from the nominal values (required unloading and stop additional generator):

$$y_0 \downarrow^1 x_1\ y_{1.7}\ y_{1.8}\ y_{1.9}\ z_{2.1}\ x_3 \uparrow^2 \omega \uparrow^1 \downarrow^2 x_{4.1} \uparrow^3 y_{3.3} \downarrow^3 x_{4.2} \uparrow^1 y_{3.4} \omega \uparrow^1 \tag{9}$$

Sync generator system with tires MSB is used to adapt the current voltage and frequency of the generator connected to the main switchboard bus parameters. Requirements are the ability to change device settings synchronization (differences between the existing values of voltage and frequency, the angle between the voltage vectors) and the presence of outputs for connection to control inputs of the excitation system of generator and engine control.

Upon reaching the synchronization conditions:

$$|U_1 - U_2| = |\Delta U| \le \Delta U_{adm}\,, \tag{10}$$

$$f_2 - f_1 = \Delta f \le \Delta f_{adm}\,, \tag{11}$$

$$|\varphi_1 - \varphi_2| = |\Delta\varphi| \le \Delta\varphi_{adm}\,, \tag{12}$$

Frequencies and angles of the vectors of mains voltages and plug the generator, respectively; and – sync settings, the system should generate a signal generator circuit breaker to:

$$y_0 \downarrow^1 x_1 \uparrow^2 \omega \uparrow^1 \downarrow^2 x_4 \uparrow^2 \omega \uparrow^3 \downarrow^3 \begin{bmatrix} y_{1.1}\ y_{1.2}\ y_{1.4}\ y_{1.7}\ y_{1.10} \\ z_{2.3} \\ (x_5 \,\&\, x_6 \,\&\, x_7) \uparrow^5 y_{3.5}\ \omega \uparrow^1 \\ \downarrow^5 \overline{x_5} \uparrow^4 y_{3.6}\ \omega \downarrow^4 \overline{x_6} \uparrow^3 y_{3.7}\ \omega \uparrow^3 \end{bmatrix} \tag{13}$$

The task of the distribution of active loads between generators operating in parallel is to measure the active power delivered by each of DGU in the total load, and the formation, if necessary, corrective action to change the frequency speed diesels. Active load distribution between the generators should be in proportion to their nominal capacity and shall not differ by more than 15% of the rated load of the larger generators or 25% of the rated load of the generator under consideration whichever is less:

$$y_0 \downarrow^1 x_1 \uparrow^2 \omega \uparrow^1 \downarrow^2 \begin{bmatrix} y_{1.7}\ y_{1.8}\ y_{1.9} \\ z_{2.1} \\ x_{8.1} \uparrow^1 y_{3.7} \uparrow^1 \end{bmatrix} \tag{14}$$

The distribution system of reactive loads should monitor reactive power supplied by the DGU to the network and, if necessary, to carry out an adjustment by changing the generator excitation. Distribution of reactive load should be proportional to nominal generator power and will not vary by more than 10% of the rated load of the largest generator reactive or not more than 25% of rated capacity of the smallest generator, if this value is less than the above:

$$y_0 \downarrow^1 x_1 \uparrow^2 \omega \uparrow^1 \downarrow^2 \begin{bmatrix} y_{1.7}\ y_{1.8}\ y_{1.11} \\ z_{2.2} \\ x_{8.2} \uparrow^1 y_{3.6} \uparrow^1 \end{bmatrix} \tag{15}$$

Expansion Modules and PLC are to be able to remote control circuit breakers and/or soft starter asynchronous motors; implementation of various sequences connecting / disconnecting electricity consumers.

Based on the analysis of the principles of marine power plants and expressions (1) – (9), (13) with respect to modes of automation can be formulated in the following theses:

a. with parallel operation of DGU voltage and frequency, measured for each of them coincide with the corresponding parameters of the shared bus (ship's network); in terms of logic, this corresponds to the equivalence of measurement and $y_{1.1}$, $y_{1.7}$, $y_{1.2}$ and $y_{1.10}$, $y_{1.3}$, $y_{1.5}$ and falsity conditions at x_1;
b. in each section there is one DGU, which is essential for this section (first come into work and runs continuously);
c. generator protection devices included in the work after it is connected to a common bus,

which corresponds to the falsity condition x_1;

d. synchronization system is needed to ensure connection to a common bus DGU and its running time is limited to the interval from starting the engine to the generator circuit breaker circuit – time the condition x_1 is true;
e. distribution system of active and reactive loads and device to control start/stop of DGU generator circuit breakers associated with all DGU this section, and for those generators, switches are closed, measuring power delivered them into the network. Thus, measurement of active and reactive power for each DGU performed only after it is connected to a common bus, which corresponds to the result of checking the condition x_1 part of DGU "false".

We can notice the following results:

-The ship to monitor network parameters may be used, as measured by the monitoring system of the main parameters of DGU (logic device obtained coincides with the expression (2).

- Most protection devices require measuring the same parameters with comparable frequency, so the implementation of all the protections of the generator can be combined in a single device – the protection system.

- Many parameters required to run the system for monitoring parameters of DGU coincide with the parameters measured for the implementation of protection of generators, however, the time averaging for their monitoring system significantly (order of magnitude) more. If you realize the measurement units required for system protection, said to her cycles and averaging these values programmatically in the interval corresponding to the time characteristics of the monitoring system, the two systems can be combined into a single unit – automation controller:

$$y_0 \downarrow^1 x_1 \uparrow^2 y_{1.5}\ y_{1.7}\ y_{1.10}\ \omega \uparrow^1 \downarrow^2 \begin{bmatrix} y_{1.5} - y_{1.11} \\ y_2 \\ z_{2.1}\ z_{2.2} \\ (x_{2.1} | \ldots | x_{2.6}) \uparrow^1 (y_{3.1} | y_{3.2})\, \omega \uparrow^1 \end{bmatrix}^{T=5\,s} \tag{16}$$

- To ensure correct operation of the load distribution systems in their design must know the exact amount of DGU, which can be connected in parallel. This condition is contrary to the principle of system development, so the modern automated SPP often used together individual units (Units job settings – tolerance of active and reactive power; blocks measuring and adjusting the active and reactive power) for each DGU bound through information channel. However, if we use a computerized control system as a subsystem of the upper level and transfer function at its reference level setting can minimize the amount of required hardware. Then the task of top level software will poll generator switches to determine the structure and management of the power plant (initiation measurements to commands on the formation of corrective actions) distribution system loads. The above decision will minimize the addition of hardware to implement remote monitoring and control processes of distribution of active and reactive loads dynamically change the distribution and transient time, remotely adjust the parameters of discrete signals used to control the frequency and voltage regulators.

- Transferring control systems of distribution of active and reactive loads on the top-level subsystem determines the necessity of their presence for each DGU, except basic. Some parameters required for monitoring parameters and ensure protection of the generator set, coincides with the measured system load distribution parameters, so protection functions can be transferred to the DGU level computerized control system, using for their implementation, as well as for monitoring parameters of DGU measured load distribution systems values. At the same time to the measured at least one of the systems parameters need to add the current frequency.

$$y_0 \downarrow^1 x_1 \uparrow^2 \begin{bmatrix} y_{1.5} - y_{1.11} \\ z_{2.1} - z_{2.2} \\ y_2 \\ (x_{2.1} | \ldots | x_{2.6}) \uparrow^3 (y_{3.1} | y_{3.2})\, \omega \uparrow^3 \\ \downarrow^3 (x_{8.1} | x_{8.2}) \uparrow^1 (y_{3.6} | y_{3.7})\, \omega \uparrow^1 \end{bmatrix} \tag{17}$$

$$\downarrow^2 x_4 \uparrow^1 \downarrow^6 \begin{bmatrix} y_{1.1}\ y_{1.2}\ y_{1.4}\ y_{1.7}\ y_{1.10} \\ z_{2.3} \\ (x_5 \,\&\, x_6 \,\&\, x_7) \uparrow^4 y_{3.5}\ \omega \uparrow^1 \\ \downarrow^4 \overline{x_5} \uparrow^5 y_{3.6} \downarrow^5 \overline{x_6} \uparrow^6 y_{3.7}\ \omega \uparrow^6 \end{bmatrix} \tag{18}$$

According to the expressions (13), (15), it can be noted that the distribution of active and reactive load, and simultaneously used for measuring the work required substantially the same parameters; System synchronization and load distribution are used consistently and require measurement of several matching parameters. As noted above, the measurement for the implementation of protection and monitoring functions of the parameters of the generator set can be made in the distribution system loads. Therefore, it is advisable to all five devices (synchronization distribution of active and reactive loads, protection and monitoring parameters DGU) combined into one device the system synchronization and load distribution:

- System for implementing the principle of expansion and development of the modules PLCs must also be implemented as separate devices.

Thus, for the automation of electric power system in the proposed method for each section, which consists of *n* and *k* DGU electricity consumers need: automation controller for monitoring network settings, monitoring and protection of the main parameters of the generator; *n*-1 systems synchronization and load distribution, additional features which will be the protection and monitoring of parameters DGU monitoring necessary start/stop additional generating units; *m* extension modules and/or PLC (the number depends on *k* and device characteristics) for state management of electricity consumers and display warning and/or emergencies

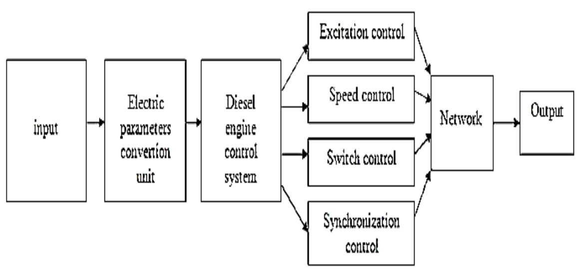

Figure 1: Ship Power Station Block diagram

The bloce diagram above describes the process of control for the SPP and the synchronization between the operation modes. It can be seen from Figure 1 that RMS phase voltage and bus main switchboard and RMS of the generator are the inputs enters the electric parameters unit which consists of the coefficient of proportionality, rectifier, integrator, a low pass filter ,pulse shaper, adder, reference voltage, the comparator after that the output (pulse control signals) of electric unit enteres logical circit unit which consists of multiplexer, ADC , shaper low frequency pulses, unit serial transceiver, I / O ports, timer-counter, amp, relay finally the user can see the output on the screen. The process is automatic, so if you want to increase or decrease input to view the parameters of the system this can be done easily.

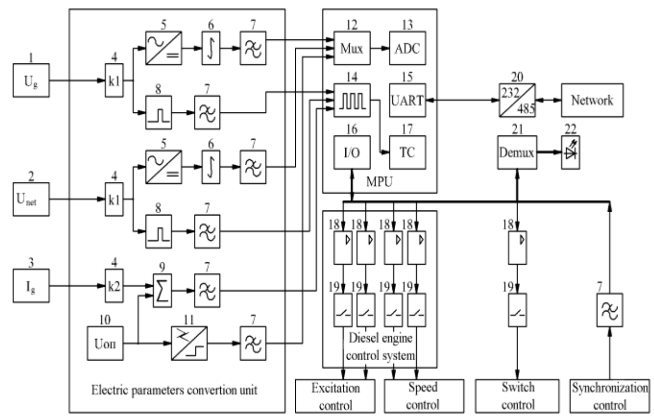

Figure 2: Control Units in Ship Power Station

Figure 2 shows a block diagram of the combined device, implemented in accordance with the above expressions, where 1 and 2 - RMS phase voltage and bus main switchboard; 3 – RMS of the generator; 4 - the coefficient of proportionality; 5 - rectifier; 6 - integrator; 7 - a low pass filter; 8 - pulse shaper; 9 - adder; 10 - reference voltage; 11 - the comparator; 12 - a multiplexer; 13 - ADC; 14 - shaper low frequency pulses; 15 - unit serial transceiver; 16 - I / O ports; 17 - timer-counter; 18 - amp; 19 - relay; 20 - interfaces RS232-RS485 converter; 21 - a demultiplexer; 22 - indicators.

Using microprocessor as the basis of the system allows you to transfer performance of many functions on the program level. This way you can control the mode of operation of the system - a waiting of the beginning of the process of synchronization, load sharing between parallel working generators, unloading the generator and stop of the diesel engine.

3. Conclusion and Future Work

Microprocessor algorithms are developed to be used in automatic control of ship power systems. Logical algorithms allow formalizing the process of analysis and structural optimization of algorithmic systems. The analysis of microprocessor automation SPP revealed the presence of hardware redundancy and ways to resolve the association of the settings of network devices, monitoring and protection of the basic parameters of the generator controller automation. In this paper logical model of SPP is developed to remote monitoring and control the parameters of SPP online.In the future, as described in the approach will be expanded and used for the formal description of the interface workstation operator and operator interaction processes with software management interface, as well as the description of the interaction between the individual elements of a distributed control system. This formally describe the different nature of the system, identify the boundaries between individual systems and the types of signals that are transmitted between the two to justify the selection of the communication interface (cable or radio) and the coding type (analog or digital), to perform the analysis of system performance

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