

Techniques for selecting topology and implementing the distributed control system network

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Abstract. On grounds of reviews devoted to flows analysis methods in the data processing networks within the automated control systems for the technological process and assessment of these methods by the selected set of requirements, one may make conclusion about expediency of using the combination of graph flow algorithms and the queueing theory. The outputs of the research concerning the impact of network dynamics on the drilling platform distributed system control quality prove the fact that the quality of the transient depends upon the frequency of discretization and intensity of flows. With increasing the intensity of flows, the static error of the control enlarges. It was concluded that in order to control the automation objects in the real-time mode it is required to minimize the delays in transmitting packets in the network.

1. Automation in industry

Automation of technological processes made possible to achieve the enhanced quality and increased profits in the various spheres of the industry where it was implemented. Simultaneously, automation of the drilling processes in the oil and gas industry is not a trivial task, the successful solution of which is impeded by a variety of factors, which are negative from the automation viewpoint. Success in this sphere allows accomplishing efficiently the most complicated tasks, namely: to explore most boreholes, drilling and exploitation of which are technically impossible or non-profitable now [1]. It is characteristic that the problems with automation implementation in the drilling process start with the aspects not closely connected with conditions or a site of extraction. Technical supply of the drilling rig comprises a set of components most of which are from different manufacturers. In the context of automation, it complicates a task greatly as cooperation under the control of the unique automation system is a requirement for the controllable equipment. High level of automation inherently assumes the realization of data exchange among all the system components and consequently their complete compatibility in methods, protocols, formats of data transfer and types of control actions as a basis for implementation of automation process.

Now communications between systems of the wellsite monitoring and management are standardized only, the transfer protocol WITSML (wellsite information transfer standard markup language) being a standard for communication. However, it is only a surface, as standard protocol for communications for the drilling rig on its own and for the whole equipment remains under question.

This paper aims at the analysis of the structure of the electric power system of a typical offshore drilling platform and at consideration of methods of selecting topology for the network of distributed system for control of elements of this electric power system at the drilling installation.



2. Description of the structure of the electric power system at an offshore drilling installation

Presence of loads with various power as well as a wide range of possible operations by drilling installations frequently results in necessity of mounting several generators. Synchronous generators produce electric power in autonomous electric power stations of the offshore drilling rigs. Due to their flexibility and versatility, diesel-generator units DGU1, DGU2 (Figure 1) etc., consisting of synchronous generators SG1, SG 2, etc. driven by diesels D1, D2, etc. are used. In general, structure of the electric power system of the offshore drilling installation provides the possibility of the simultaneous operation of all the SG that allows summing up their power on the global bus of the main switchboard (MSB). Thus, under standard conditions for the electric power plant it is possible to choose the optimum structure and to minimize the financial expenses for the power generation. Although with such structure of the electric power plant, availability of the systems for distribution of active/reactive power operating with parallel switch of generators as well as protection system is required.

All the plant generators are supplied with field voltage u_f , and all the diesels are supplied with fuel with discharge rate g (Figure 1) [2,3]. For DGU, which is driven in the group of shunt generators, automated voltage regulating systems and frequency regulating systems are used. For DGUs, which are driven in the group of shunt generators, active and reactive powers are regulated by means of regulators respectively, an automatic regulator of active power and an automatic regulator of reactive power ARAP (an automatic regulator of the active power) and ARRP (an automatic regulator of the reactive power), acting upon the diesel via the fuel system and upon the generator – via the excitation system. Thus, use of electronic control systems allows automatically sharing of active and reactive powers between shunt generators.

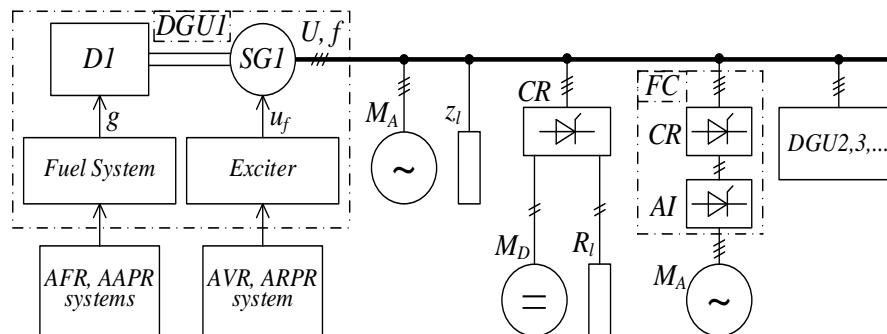


Figure 1. Systems of automated regulation of electric power parameters in the electric power system of the autonomous drilling installation: *DGU1* – diesel-generator unit (diesel *D1* + generator *SG1*); *AFR*, *AVR* – systems of automated regulation of frequency and voltage in the synchronous generator, *DGUn* – diesel-generator unit (diesel *Dn*+ generator *SGn*, where *n* – is a number of *DGU*); *AFR*, *AVR*, *AAPR* and *ARPR* – systems of automated regulation of frequency, voltage, active and reactive capacity of a synchronous generator; *MA* and *MD* – ac and dc motors; *zI* and *RI* – resistance of static load on ac and dc; *CR* – controlled rectifier; *AI* – autonomous inverter (of voltage or current); *FC* – frequency converter.

It should be noted that the autonomous electric power system of the drilling installation is distinguished by a restricted power of the electric plant; commensurability of the converting load power of the variable speed drive and electric plant capacity; distinctive variable character of loads, great change of maximum loads depending on both current performance of the borehole and lithological conditions of drilling; constant changes in configuration of the electric power system of

the electric technical complex of the drilling installation connected with the number of operating electric drives due to the conditions of drilling and with changes in the number of shunt synchronous generators due to the drilling conditions. All these require reliable and accurate performance of automated control means for the elements of the electric power system in the drilling installation.

If the energy generated is more than sufficient for switching the powerful load, load of generators is less than certain values, a generator is removed for running in parallel and diesel is stopped.

3. Information support for the drilling rigs distributed systems

The control system for the autonomous electric power network is considered as an integrity of microprocessor systems distributed through the production premises and united by bulk, ring or any other sign. It should provide centralization of the control (collection, processing, submission of the information to the staff at the control points on the technical state of the equipment and quality of technological processes, which should be controlled automatically and remotely). Thus, the system is of a distributed type by arrangement and by topology. The structure of the commutation lines between the computer elements (topology of data network) is determined by considering, as a rule, feasibility of efficient technical implementation. An important role in selecting the network structure is played by analysis of flow intensity data while solving the control problems.

Assessment of the electric power control system in an offshore drilling rig from the hierarchy approach point of view makes possible to determine the topology when creating the control system and to distribute the load for the information channels uniformly and proportionally.

Let us form the control system by the hierarchy principle [4]. In the event of failure of the higher-level elements, the performance of the electric power system is provided by means of the lower level elements [4, 5].

In order to provide the high reliability of the control system, the network should have high connectivity. In case of failure of certain components, the total operability of the control system should be maintained. The choice of network topology is determined, largely, by availability of additional connection between nodes. Thus, linear topology, which is a single-dimension array, combined into a chain, has a number of drawbacks: the time of passing between two nodes depends on the distance between them, and failure of one of the nodes results in failure of a message sending. The use of the ring topology is also expedient as it is not capable for extensibility (addition of a new node requires disassembling of the network), load on the transmit channel between various nodes will be different, backup communications are not available. As the drilling rig electric power control system is formed by the principle of the hierarchy, it is reasonable to use tree-type topology.

If the tree topology is used, local control systems for nodes in every DGU [2] are connected via flow routers for the local automatic means with the systems of the automatic control of every DGU and with flow routers for the local automatic means of the other DGU. These functional complexes are connected in a similar way with each other via individual flow routers for the functional complex control devices and controlled by the complex control system. Local systems, designed, as a rule, on the microprocessor basis, use industrial interfaces CAN, RS485; and the complex control system, in its turn, is reasonable to be implemented on the ground of the microprocessor systems of the personal computers enabling to integrate the complex control system under review into the overall ecosystem of the electric power plant of the drilling rig, into existing software-hardware automated control systems for technological processes, etc. Therefore, it is expedient to use Ethernet network at the high level, taking into consideration known specific features and drawbacks: the microprocessor automated control system (ACS) has finite response speed, operation execution time being able to change quickly due to a set of factors; virtual ACS operate with discrete signals, both in time and in amount, therefore replacement of discrete signals for continuous staircase ones is not quite adequate; analogue-digital transformation of signals entails certain distortions in the controlled signal that is connected with the limited band of transmission.

The latter becomes less significant due to the distribution of local control functions and regulation between local microprocessor systems.

4. Methods of network arrangement selection

The main idea of methods for selecting the network arrangement is to analyze the required characteristics of the network, to assess the priority of every network, to choose value judgement for any of the characteristics, to analyze the given battery of parameters and to determine the minimum weight network as the most appropriate for the problem set [6-8].

The methods involve performing the following steps:

- To generate a range Ψ of possible network interfaces;
- To generate a range Ω of analyzed parameters in the network interfaces;
- To generate a range of weights V , where $v_i \in V$, is weight assessment of the characteristics $\omega_i \in \Omega$;
- Reset to zero s_i , for all $s_i \in S$;
- To build up a set of total weights S , where $s_i \in S$, is the total weight of the network interface $\psi_i \in \Psi$;
- To choose the parameter $\omega_i \in \Omega$, $s_i = s_i + F(O(\psi_i \in \Psi, \omega_i \in \Omega)) \cdot v_i$, where $O(\psi_i \in \Psi, \omega_i \in \Omega)$ is a function equal to deviation of the network analyzed parameter $\psi_i \in \Psi$, from the parameter reference value $\omega_i \in \Omega$; $F(x)$ is a serial number in the ascending-sorted set of values for the function $O(\psi_i \in \Psi, \omega_i \in \Omega)$;
- To eliminate ω_i from Ω , if $\Omega \neq \emptyset$, go to paragraph 6;
- To choose $s_{\min} = \min_{s_i \in S} s_i$, that means that the network interface ψ_i is best suited for this problem of automation.

Table 1 is a comparative table of parameters of the most popular local microcontroller networks in respect of the busbar characteristics.

Table 1. Specification comparison of busbars.

<i>Busbar type</i>	<i>RS-485</i>	<i>I²C</i>	<i>LonWork</i>	<i>CAN</i>	<i>MicroLAN</i>
Max length of wire, m	2000	8	72	40	300
Max number of attachment units	32	14	127	127	2 ⁵⁶
Mains supply	-	+	-	-	+
Number of wires in a busbar	2	4	2	2	2
Availability of stand-alone devices	-	-	+	-	+

In analyzing networks as well as their performance and search for optimal data transfer routes, it is helpful to apply the graph theory [6]. The network, may be represented as graph $G(V, U)$, where V is a set of graph vertexes, U is a set of graph arcs. Let set V consist of the network nodes, the network manager as well as points where the direction of the network information flow changes. The weight of the arc in the graph is as follows [7]:

$$u_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}, \quad (1)$$

where x_i, y_i are Cartesian coordinates of vertex v_i ; x_j, y_j are Cartesian coordinates of vertex v_j . In [8] the notion of the vertex separation number is introduced:

$$C(v_i) = \max_{v_j \in V} [d(v_i, v_j)], \quad (2)$$

where $d(v_i, v_j)$ is the shortest distance between vertexes i and j .

$$d(v_i, v_j) = \sum_{k, j \in T_{ij}} u_{kj}, \quad (3)$$

where T_{ij} is a graph simple path $G(V, U)$ with the beginning in vertex v_i and the end in vertex v_j [7-9].

Thus, the length of the maximum segment is as follows:

$$C(v_m) = \max_{v_j \in V} [d(v_m, v_j)], \quad (4)$$

where v_m is the vertex where the network manager is located.

The graph radius, being the minimum one of the eccentricities of the connected graph vertexes, is determined with the expression [9]:

$$R_0 = \min[d(v_m, v_j)]. \quad (5)$$

The use of the graph theory makes it possible to search the optimal route for transfer of the information control packets. In searching this route, such options as reliability of the data transfer, network delay, discard probability, channel loading, etc. should be taken into account.

5. Setting the network load simulation problem

The main parameter of the data network is the network traffic. In this system, traffic is a random fuzzy variable. While studying and assessing the performance of the proposed model, one may make load forecasts both for certain network channels and for the network as a whole. This simulation system may be a part of the computer-aided design engineering of data-processing networks.

Simulation time means step-by-step time, i.e. network traffic changes at all the network nodes with every step. Alternators of the network traffic are divided into the following types: expansion-operating generators (generators that go off just once per a finite number of steps of time); and continuously operating ones.

At each regular moment of the simulation time, the unit of the flow corresponding to the port acts at each of the node ports and communication module. The frequency of occurrence of each of the units depends on intensity specified for each of the units as a fuzzy random value. Based on this sequence, integral assessments of the total load of the channel, sub-network as well as the network as a whole may be produced. The methods are given below. The following factors are assessed for every network process:

- The volume of the transmitted data for each class of service;
- Uniformity of the flow of the transmitted data for each class of service;
- Distribution of the operation intensity for 24 hours.

The channel for data transmission is assessed according to:

- Maximum utilization of the channel;
- Reliability of transmission via the channel;
- Dependence of transmission reliability on the traffic volume.

Assessment is produced as a fuzzy random value (FRV) of the following type:

$$T_g = \{A1/P1, A2/P2, A3/P3\}, \quad (6)$$

where $A1, A2, A3$ are certain fuzzy sets and $P1, P2, P3$ are a fuzzy membership function.

In engineering systems the description of parameters as a tree-type classification is widely spread. For the sake of convenience while setting these parameters by experts, it is proposed to apply such arrangement in setting the terms for every linguistic variable. As an assessment, the main fuzzy set and values specification with a various range of detailing are used. The sequence of such arrangement is as follows:

- Linguistic variables, required to assess the flow, are identified;
- A number of terms is selected for each linguistic variable and physical values for their marginal conditions are determined;
- For qualitative evaluation a main fuzzy set and qualifying ones with a different refining grade are specified;
- The membership function for the fuzzy set is defined for each term.

The linguistic variable is also defined as a tuple $\langle p, T, X, G, M \rangle$, where p is the title or name of the linguistic variable, T is a ground term-set of the linguistic variable or a set of its values (terms), any of them is a title of a certain fuzzy variable; X is a scope of fuzzy variables, which are included into the definition of the linguistic variable p ; G is a syntactic procedure which describes the process of new values formation for this linguistic variable from the set T ; M is a procedure which makes possible to match a certain substance for every new value of this linguistic variable by forming a relevant fuzzy set.

6. Conclusion

This results in great excess of hardware facilities in the electric power system and its increased cost. Furthermore, the main criterion for choice of topology is its efficiency requirement and cost, the expected upgrading and limits of the existing technologies are of secondary significance. Based on the review of the methods for analyzing the flows in the information processing networks within the automated control systems for the technological process and assessment of the reviewed methods by the selected set of requirements and analysis, one may conclude that it is reasonable to use a combination of graph flow algorithms and queueing techniques.

Moreover, the proposed techniques for choosing the network arrangement may be used which is reasonable to apply in conjunction with modelling of the load for the network under review.

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