SIMULATION OF UNAVAILABILITY OF THE OFFSHORE UNIT'S POWER PLANT SYSTEM WITH USE OF SELECTED ALGORITHMS

Leszek Chybowski*

(Technical University of Szczecin, al. Piastów 19, 70-310 Szczecin, Poland)

Zbigniew Matuszak**

(Maritime Academy of Szczecin, ul. Wały Chrobrego 1-2, 70-500 Szczecin, Poland)

Abstract: *The selected power plant system of a multi support offshore vessel exploring seabed was used for a simulation of the unavailability of the system. The analysis was performed on the basis of a fault tree for fuel supply system by the upper bound approximation and with the use of the exact calculation algorithm.*

Key words: *ship power-propulsion system, fault tree, simulation of power plant unavailability*

1. Introduction

Seas and oceans are bigger part of the surface of our planet and they are the environment of work for transport and fishing ships, but also for various special objects like oil rigs, drilling platforms, FPSO's (Floating Production, Storage and Offloading units) and offshore multi support vessels, which are units worked for crude oil and natural gas exploration. Safety of the navigation and operating of all of these objects is very important because of the potential chance to cause the environmental catastrophe, e.g. spill of oily products into the sea environment. With other matter, there is the risk of the loss of health and lives of crewmembers and passengers of these units, also the loss of the considerable value of material property. All these factors are concentrating especially round offshore ships, because of big number of crewmembers (often a few hundred persons), and specificity of executed work, these vessels require very strict procedures of safety and reliability of their work.

1———————————

* M.Sc., Marine Engineer

** Ph.D., D.Sc., Maritime Academy Professor

In the paper the attempt at estimation of unavailability of selected marine power plant system installed onboard the ship for multi support operation, utilizing the fault trees for this system and selected evaluation methods (Upper Bound Approximation and the method based on the algorithm of the exact calculation called ERAC). Two different models are used in analysis. The *classic model*, where elementary events are described by the constant value of the function of unavailability and *time depended model* with failure process described by exponential distribution. Values of the function of failure intensity were estimated for each element on the basis of the observation of damage moments. Some of data were given in the situation from reliability databases [11, 13, 14].

2. Presentation of the analysed object

Analysis has been done on example of marine power plant systems fitted onboard offshore multi support vessel [4, 6, 8] for assisting in exploration of the sea bottom, mainly for executing constructional works on mining and processing subsea installations (fig. 1).

Fig. 1. View of multi support vessel

The unit is a dynamically positioned reeled flex-lay / pipelay and diving support ship equipped to lay rigid pipe of up to 14" diameter which can be reeled on to the ship at a shore based spooling facility or lifted on to the ship as a full reel. The reel lay system also allows for installation of flexibles and umbilicals. In addition, the saturation and air dive spreads onboard the presented ship gives her the capability to supply a full range of construction services. During operations unit is positioned by automatic dynamic positioning system Simrad ADP 703 type with the backup ADP 701 system. During DP operations ship is utilizing for propulsion two aft azimuth thrusters Ulstein TMC92 type (each with power rate 1470 kW) and every of the three bow thrusters Ulstein 375 TV type (each with power rate 1100 kW). This ship is made and operated according the third consequence class, it means that level of redundancy of the vessel's equipment in terms of offshore standards is the highest, what is very important when "operations where fatal operating accidents or severe pollution and damage with large economic consequences are probable results of loss of position".

Simplified diagram of the marine propulsion and power unit were presented in the figure 2. This unit and his auxiliary installations are different from installed onboard transport ships, because of the very high level in the structural, functional and distributed redundancy. Vessel has three engine rooms. There is original engine room on the aft and two new forward engine rooms (port and starboard). The aft engine room contains two main engines Wichman 5AX type main engines (rated at 1000 kW each drive a controllable pitch propeller through pneumatically operated clutch). There are also three auxiliary diesel generators Delco E7092M3 type driven by Detroit Diesel 16 V-71 Turbo (rated at 380 kW at 1760 rpm). This alternators supply original "old" bus 440 V. There is also Detroit Diesel 16 V-71 powered stern tunnel thruster (skeg) in the aft engine room.

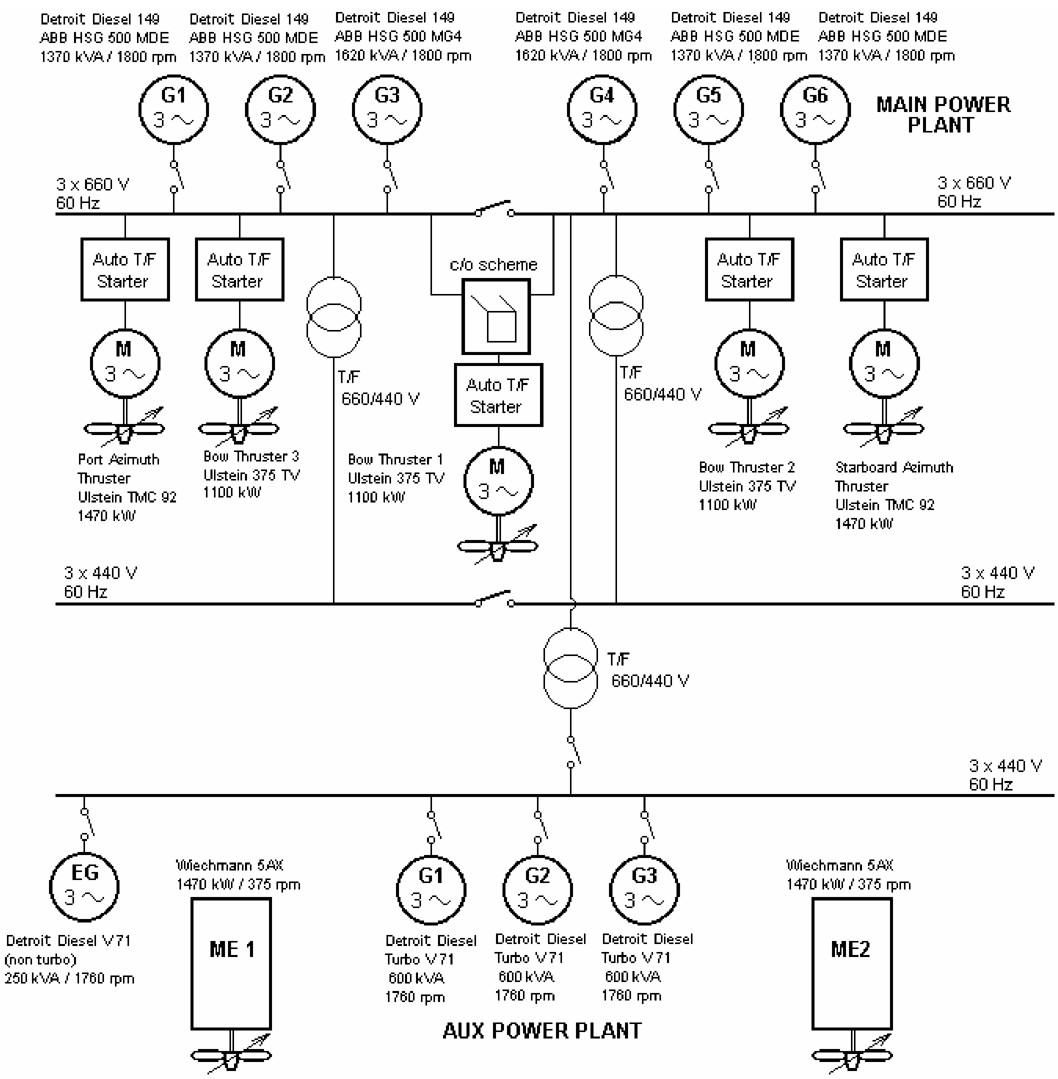

Fig. 2. The power-propulsion system of offshore vessel

All the engines in the aft engine room are supported by the aft engine room essential services. Once set up for class 3 operations, the new engine room and old engine room systems can operate without any mutual support. The port and starboard engine rooms (main power plant) are similar and totally separate from each other with respect to fuel, lube oil, cooling water, air and power supplies. Each forward engine room contains two Detroit Diesel 149 engines driving ABB alternators HSG 500 MDE type; each rated at 1370 kVA at 1800 rpm. A third set in each forward engine room is Detroit Diesel 149 engine driving an ABB alternator HSG 500 type, rated 1620 kVA at 1800 rpm.

The diagram of fuel supply system of the main power plant, which is object of analysis, was presented in figure 3. The observation and registration system components failures were being preceded during three years of operating ship at sea. Because of the high level of redundancy and operational procedures forcing frequent control of the technical state of machines and devices, the number of observed failure states was low. Failure intensity and operating unavailability for some system elements where taken from literature.

Each of the forward engine rooms has its own fuel supply system. Each set of three diesel generators MG1, MG2, MG3 – starboard; MG4, MG5, MG6 – port) has its own diesel supply tank (TP, TS). Each tank contains 28 m3 of diesel oil and is fitted with a low level alarm. Fuel is supplied through a quick closing valves (V1P, V1S) in the engine room service tank to the engine room cross main feeding three engines in the respective engine room. .

Subsystem of fuel supply for each of six diesel engines contains inlet valve (VS1, VS2, VS3, VS4, VS5, VS6), engine driven booster pomp (P1; P2; P3; P4; P5; P6), pump-injectors units (1I1, 1I2...1I16; 2I1, 2I2...2I16; 3I1, 3I2...3I16; 4I1, 4I2...4I16; 5I1, 5I2...5I16; 6I1, 6I2...6I16), strainers (S1; S2; S3; S4; S5; S6), fine filters (F1; F2; F3; F4; F5; F6) and fuel junction blocks (R1; R2; R3; R4; R5; R6), outlet valve (VD1, VD2, VD3, VD4, VD5, VD6).

Functional structures of energetic fluids flow were presented in figures 4 and 5, for port and starboard sides respectively. Used symbols are same as in the figure 3. Dark elements are noting components, which where down during observation system in operation.

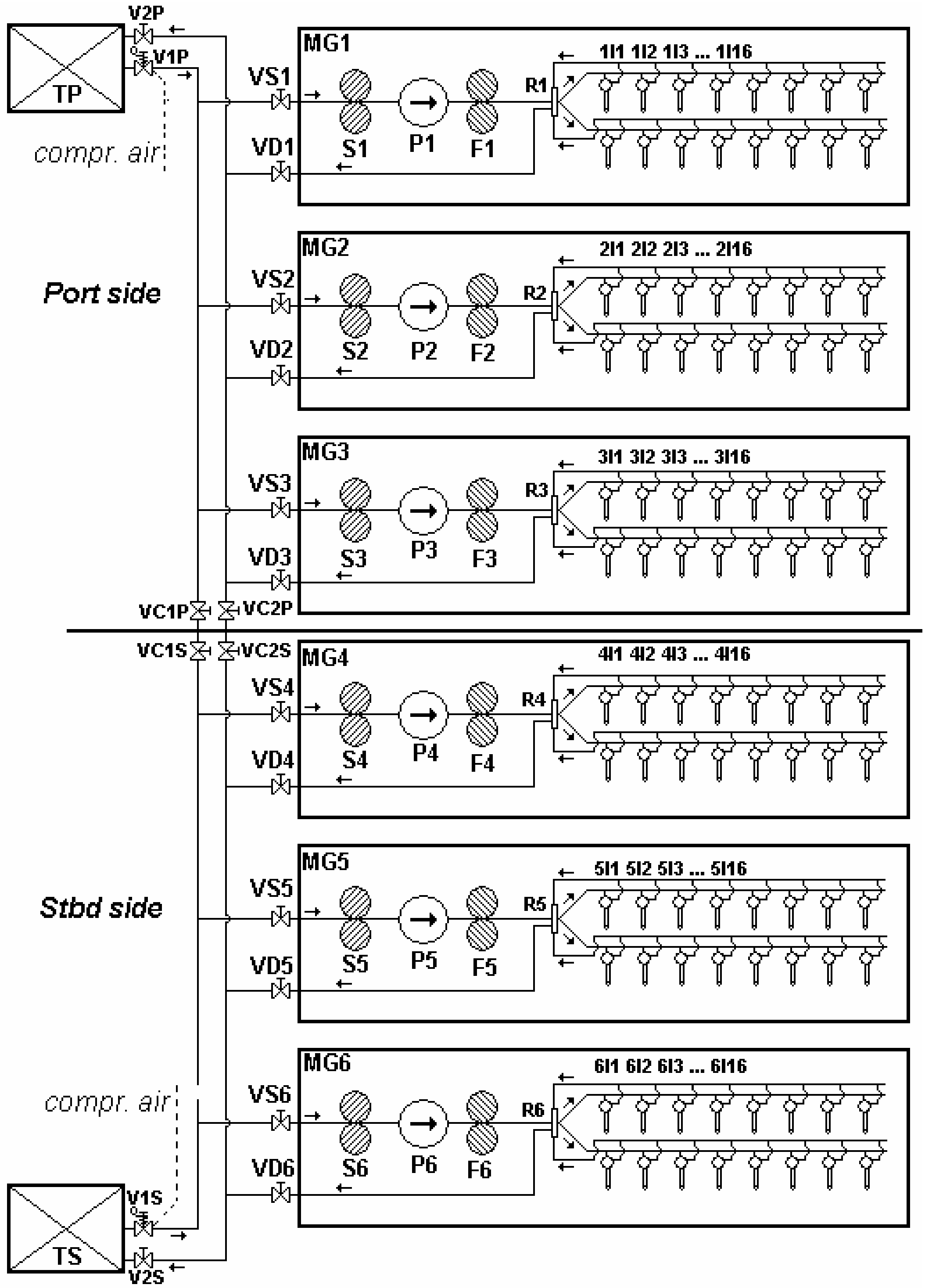

Fig. 3. The fuel system of the power-propulsion system

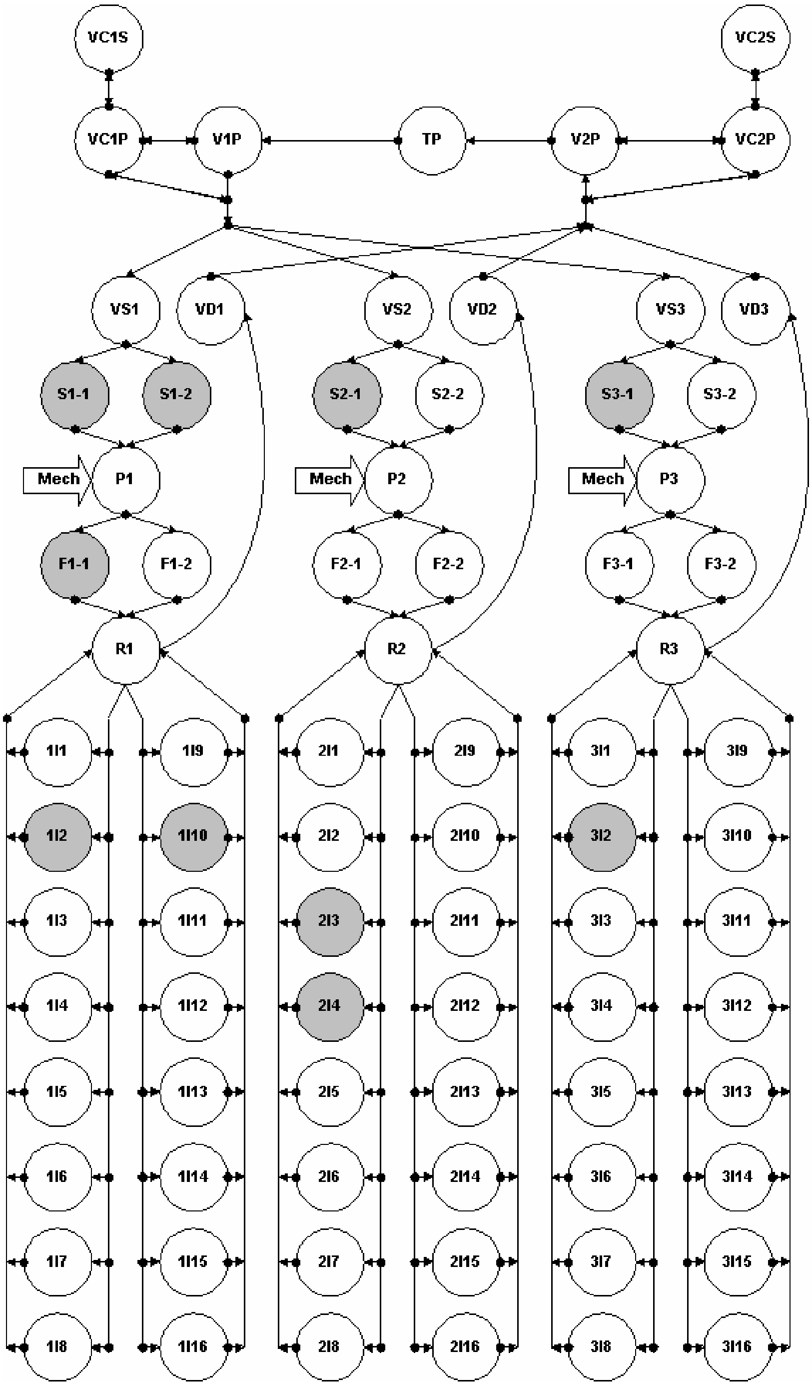

Fig. 4. Functional structure of energetic fluids flow in the port main engine room fuel supply system

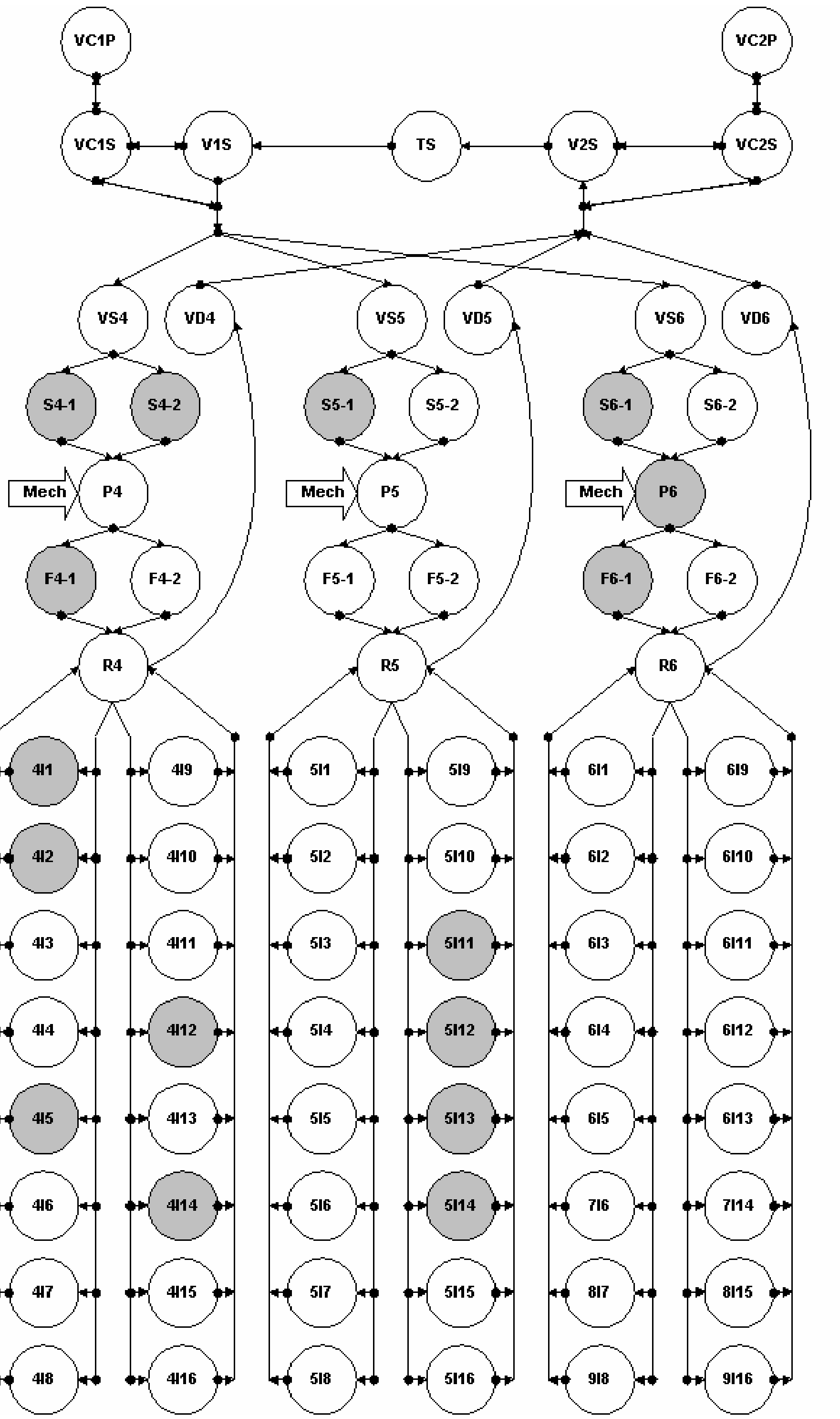

Fig. 5. Functional structure of energetic fluids flow in the starboard main engine room fuel supply system

3. The application of fault tree to analyse of the main power plant fuel supply system

Elements of every marine power plant system are undergoing periodic reviews, check-ups and maintenance services, in accordance with requirements of manufacturers, classification societies and the ship owner's recommendation. Main operational activities and suitable lengths of periods between reviews, in fuel supply system were presented in the table 1.

Table 1. Recommended periods between planned maintenance work for fuel system elements of the generating set engines

Element	Maintenance work	period between services
Booster pump	Exchange of the element for new (within the confines of the main service)	12 000 h*
Pomp-injector unit	Tune up	3 000 h*
	Exchange of pump-injectors	6 000 h*
Strainers	Cleaning	500 h*
Fine filters	Filtering cartridges exchange	500 h*
Pipelines and valves	Exact control of fittings	12 months
Pipelines and valves	General check	24 h
Service tanks	Draining, the external visual inspection and check of the diesel oil level and the transport of the fuel	24 h
	Review according to regulations of the classification society (internal audit for presence of damage to the structure of the container)	60 months

* – counter working time for given engine.

Services of active elements were being done according to the time of their real operating (on the basis of devices counters), however passive elements of the system according to the calendar time. In case of offshore ship service time can be changed according to temporary one of engine rooms is off (when ship is in the port), different amount and configuration main generators in working state, different between calendar time and time from maintenance planning software (30 days for counters update in present configuration of AMOS), impossibility of repair because of other requirements (breakdown, DP procedures, lack of spare parts, storm etc.)

In tables 2 and 3 taken values of failure intensities of fuel supply system elements were presented. On the basis of data from tables 2 and 3, unavailability of elements of the system for selected mission times were calculated. Estimated unavailability values were shown in the table 4.

Table 2. The adopted values of failure intensity of fuel system elements of the generating set engines. Continuous wear process

Element	Parameter λ of exponential distribution		Remarks
	[failures./h]	[failures./ 10^6 h]	
Booster pumps	$5{,}00 \cdot 10^{-6}$	5	One failure during observation (value taken from external database [11])
fuel junction blocks	$3{,}00 \cdot 10^{-6}$	3	Leak, contamination of pipes (value taken from external database [14])
Pomp-injectors units	$5{,}54 \cdot 10^{-6}$	5,54	Failure during operation (on the basis of observation)
Strainers	$4{,}17 \cdot 10^{-4}$	416	On the basis of observation
Fine filters	$4{,}17 \cdot 10^{-4}$	416	On the basis of observation

Table 3. The adopted values of failure intensity of fuel system elements of the generating set engines. Operation on demand

Element	Parameter λ of exponential distribution [failures./h]	Remarks
Valves	$1{,}00 \cdot 10^{-4}$	Valve failure (on the basis of [13])
Service tanks	$1{,}00 \cdot 10^{-7}$	Damage of tank structure, empty tank (on the basis [11])

Table 4 Estimated values of operational unavailability of fuel system elements

Element	Unavailability of element	
	Mission time 500 h	Mission time 6000 h
Booster pumps	2,50E–03	3,00E–02
fuel junction blocks	1,50E–03	1,80E–02
Pomp-injectors units	2,77E–03	3,32E–02
Strainers	2,09E–01	2,09E–01*
Fine filters	2,09E–01	2,09E–01*

* for filters (except some of comparative analyses) at the simulation for 6000 h was engaged time of the 500h mission for the model of the constant probability, for the simulation with time-dependent model were assumed that filters were characterised as repairable elements.

For presented fuel supply system two different fault trees [2, 5, 7, 12, 14] were constructed (for two different engine rooms operational states: when crossover valves are opened e.g. during stay in the port; and crossover valves are closed, what is required during DP class 3 operations).

Fault trees are presented in figures 6 and 7. Symbols are same in previous figures. In both models for simplification some parts of tree is changed on transfer symbol, which is connected with fuel installations on diesel engines (transfers: MG1, MG2, MG3, MG4, MG5, MG6). Example subtree represented by transfer is presented in figure 8 (example subtree for MG1)

The analysis was executed on the basis of constructed trees taking as input data, failure measures from tables 2, 3 and 4. The analysis was based on the *CARA-FaultTree* computer code from *Sydvest Software* [9] and for some of analysis (auxiliary calculations) *MS Excel* was helpful. Main reason of calculations was estimation of unavailability of selected marine power plant system. Analyses were performed with using two algorithms i.e.: upper bound approximation *UBA* approximation and with method based on the algorithm of the exact calculation *ERAC*.

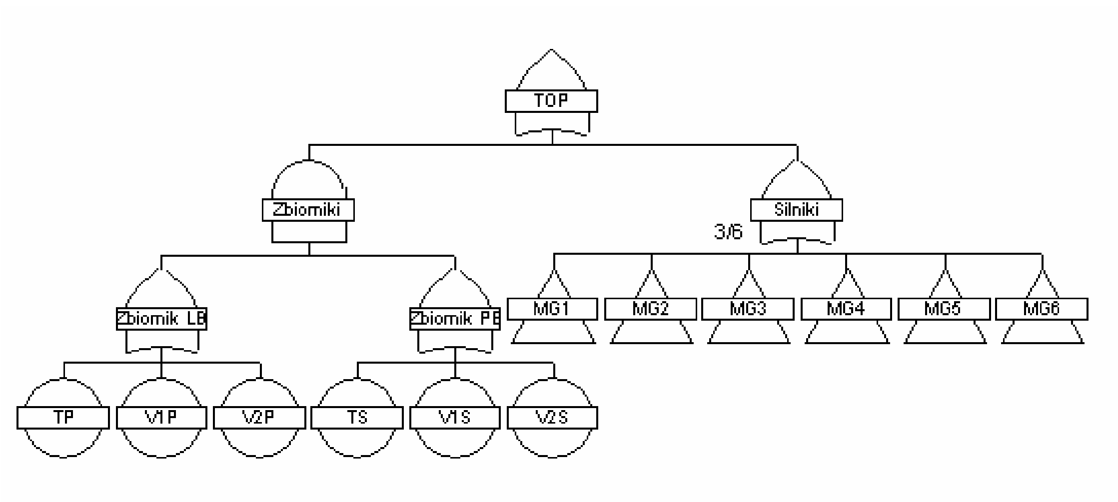

Fig.6. A fault tree for the fuel system of the generating set engines – valves separating power plants are open

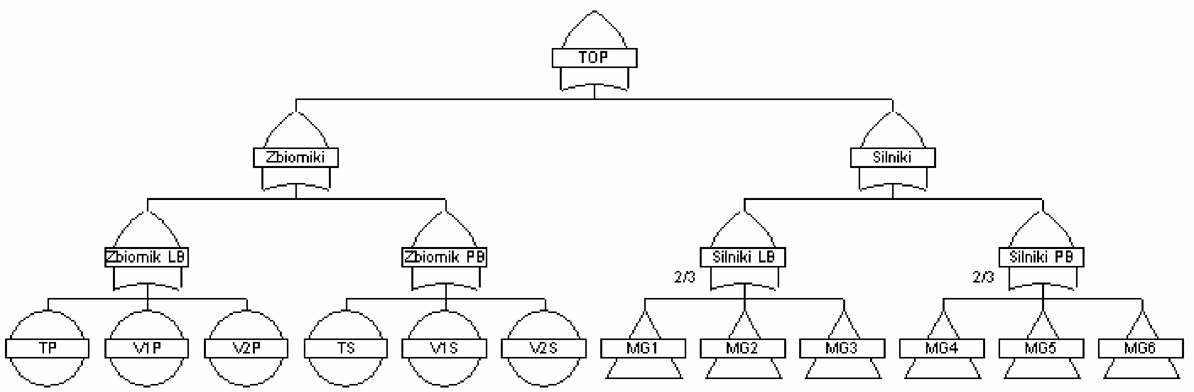

Fig. 7. A fault tree for the fuel system of the main generating set engines – valves separating power plants are closed

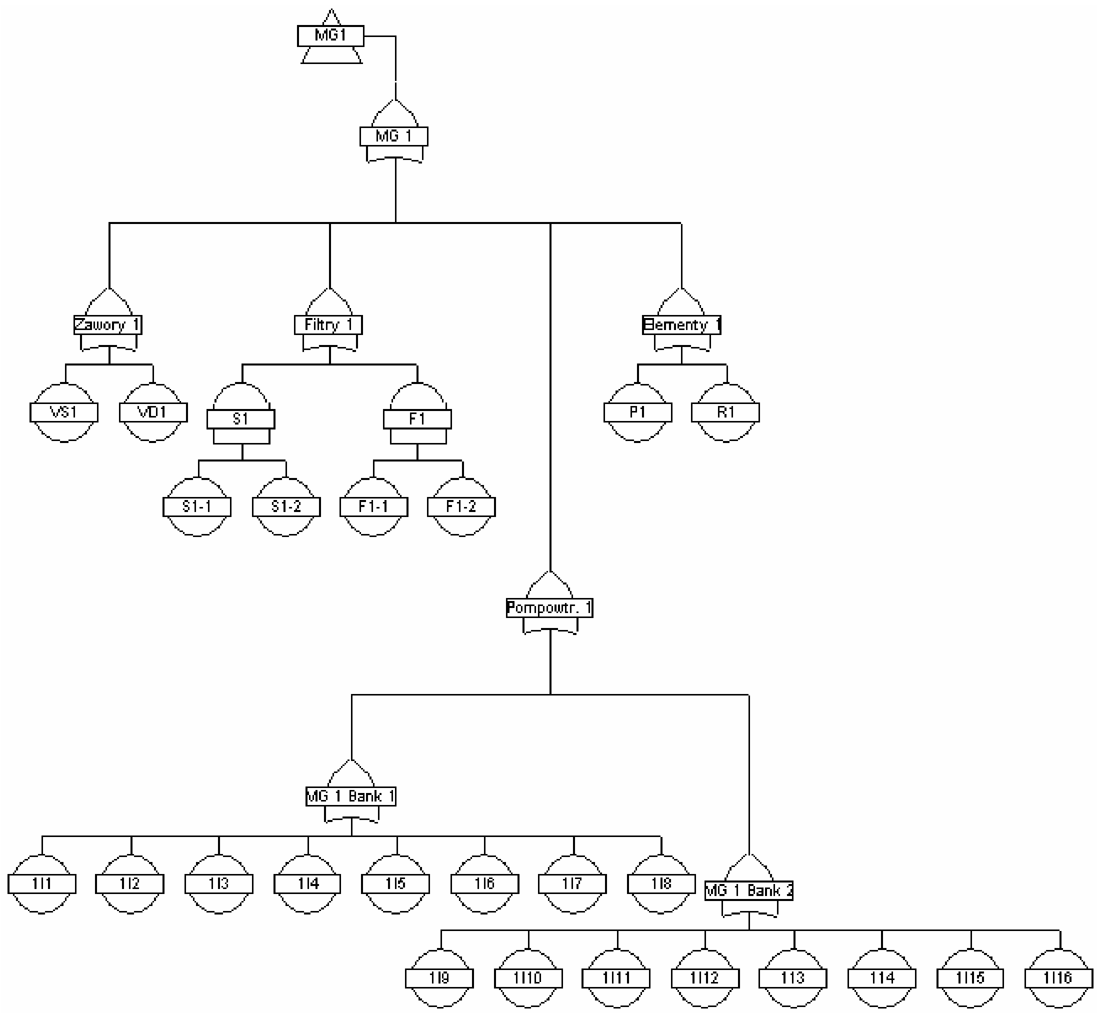

Fig. 8. A fault tree of the fuel system of an electric power plant engine
(sub-tree of engine local installation – a case of MG1)

The following formula provides an upper bound for $Q_0(t)$, and is usually a satisfactory approximation to $Q_0(t)$. We assume that the system unavailability $Q_0(t)$ can be approximated as the ip-function [3] of the minimal cut sets unavailabilities $Q_k(t)$. Let the minimal cut sets of the tree be denoted $C_1, C_2, \dots C_n$. Every system is down if and only if one or more of minimal cut sets is down. By the assumption of independence of input events, unavailability of k-th minimal cut set is given by product of events unavailabilities q_i in given cut set:

$$\breve{Q}_k(t) = \prod_{i \in C_K} q_i(t) \tag{1}$$

If the cut sets were disjoint, then they would be stochastically independent and we have:

$$\breve{Q}_o(t) = \breve{Q}_{0UBA}(t) = \coprod_{k=1}^{n} \breve{Q}_k(t) = 1 - \prod_{k=1}^{n} [1 - \breve{Q}_k(t)] \tag{2}$$

In general, however, the minimal cut sets for marine systems are not disjoint. In this case we always have:

$$\breve{Q}_o(t) \leq 1 - \prod_{k=1}^{n} [1 - \breve{Q}_k(t)] \tag{3}$$

and that in fact $Q_0(t)$ approximately equals the right hand side of (3), at least when the $q_i(t)$'s are close to 0. It should be noted that the inequality (3) could be also applicable when the input events in the fault tree are positively dependent (so-called associated) rather than independent.

One of alternatives for upper bound approximation is the ERAC algorithm (Exact Reliability/Availability Calculation), which was developed by Aven [1]. The ERAC algorithm is based on a decomposition method by Doulliez and Jamoulle [10], originally designed for transportation networks. A modification of Aven's approach is used in CARA-FaultTree, which was use by author of paper for unavailability marine systems simulations.

We assume that fault tree have n independent input events. Let $y = (y_1, y_2, \ldots y_n)$ denote the random state vector of the input events, where y_i is equal to 1 when i-th input event occurs and 0 otherwise. Now, let A denote all the states y of the fault tree such that the TOP event occurs. The probability $Q_0(t)$ of the top event is thus determined by:

$$\breve{Q}_o(t) = \breve{Q}_{oEXACT}(t) = \sum_{\bar{y} \in A} P[\bar{Y}(t) = \bar{y}] \tag{4}$$

if assume, that:

$P[Y_i(t) = 1] = q_i(t)$

$P[Y_i(t) = 0] = 1\text{-}q_i(t) = p_i(t)$

then probability that system is in state given by vector y from set A is given by:

$$P[\bar{Y}(t) = \bar{y}] = \prod_{i=1}^{n} p_i(t)^{1-y_i} q_i(t)^{y_i} \tag{5}$$

The ERAC algorithm and most of its competing algorithms are based on formula (5). The prime objective of all of these algorithms is to determine the set A as efficiently as possible. It is observed that A is always a subset of the vector interval *[0, 1]*. In ERAC the set A is determined by successive partitioning of this interval in so-called acceptable and non-acceptable states.

Simulations were carried out at the assumption of:

- full availability of the system in the moment of beginning of the observation;
- all elements are classified as unrepairable
- time between planed maintenance services is corresponding to the time of the simulation (table 1);
- exponential distribution of periods between elements failures;
- the time of the simulation on the basis of the observation for services 500 h and 6000 h, as equal 1000 h and 6500 h respectively;
- events (faults) are statistically independent;

- maximal error of numeric analyses for the *ERAC* algorithm equal $E_{ERAC} = 10^{-06}$;
- accuracy of the measurement 1 h;

Effects of the estimation of unavailability of the analysed system are presented in figures 9-14. Estimation was done for different states of system (crossover valves opened – *Pol* and crossover valves closed *Roz*), two different methods (*UBA* and *ERAC*), different models of failure i.e. time-dependent model *L* (tab. 2, 3), and classical model of the constant probability of element failure *C* (tab. 4). All symbols are presented in accordance to methods and models presented previously.

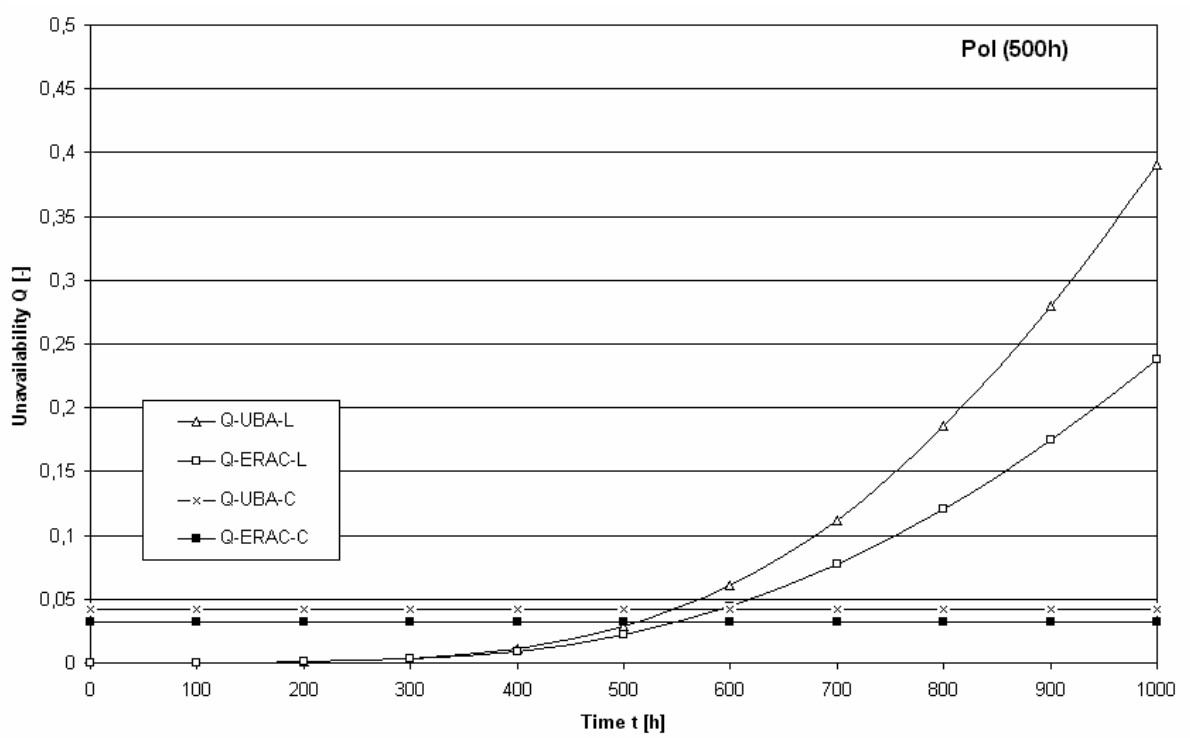

Fig. 9. The results of connected power plants simulation *Q(t)* for 500 hours

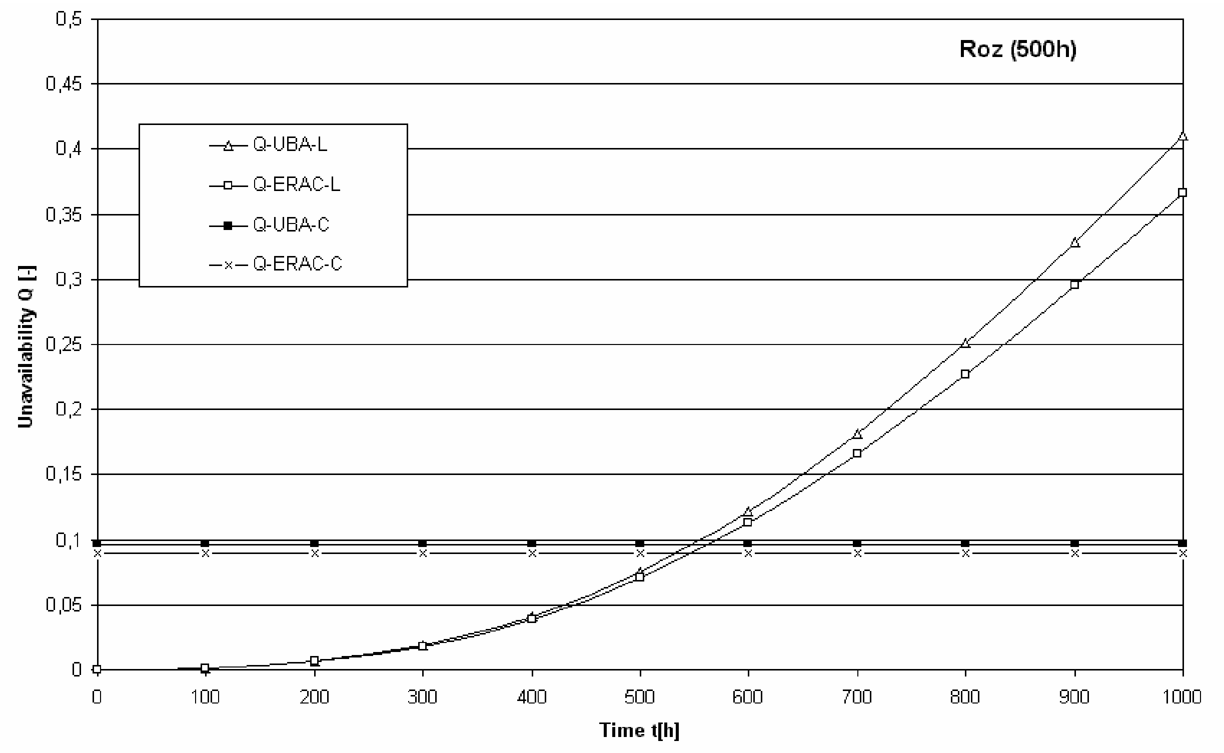

Fig. 10. The results of separated power plants simulation *Q(t)* for 500 hours

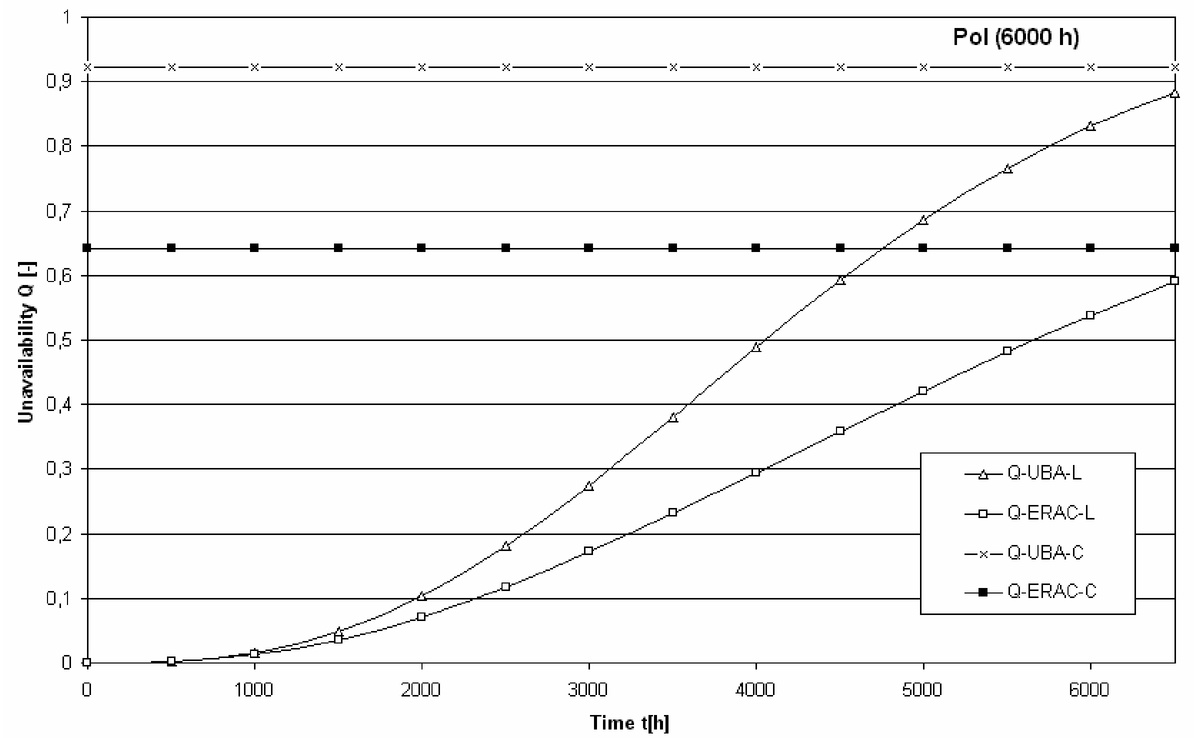

Fig. 11. The results of connected power plants simulation *Q(t)* for 6000 hours

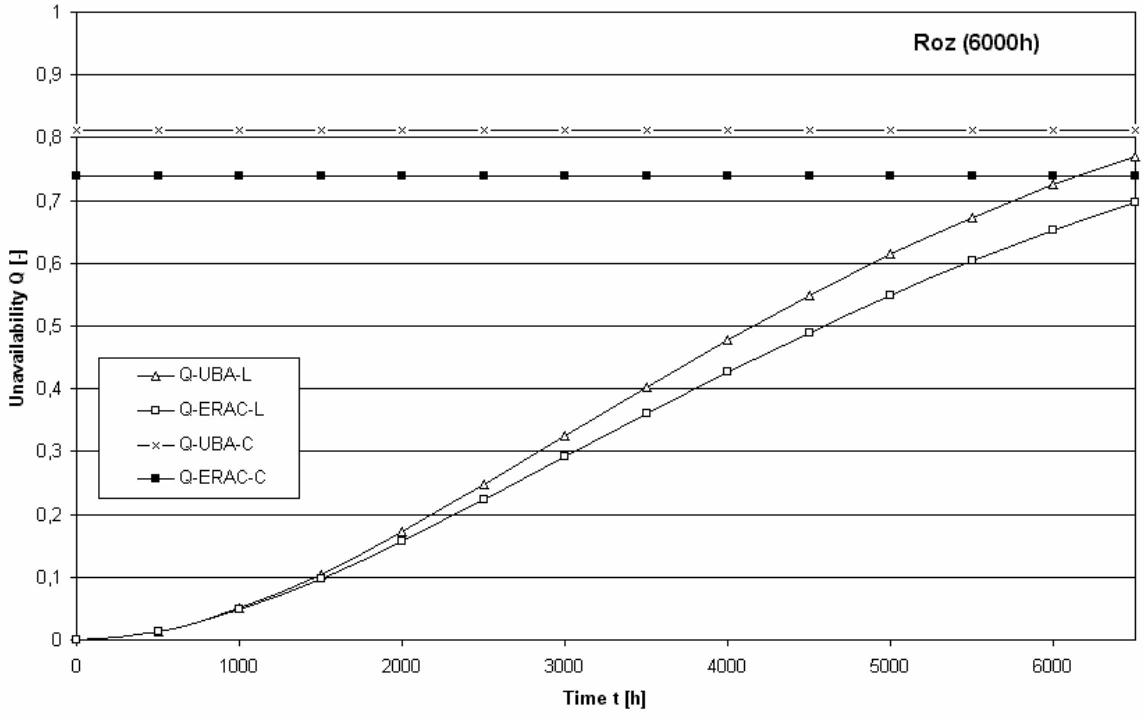

Fig. 12. The results of separated power plants simulation for *Q(t)* 6000 hours

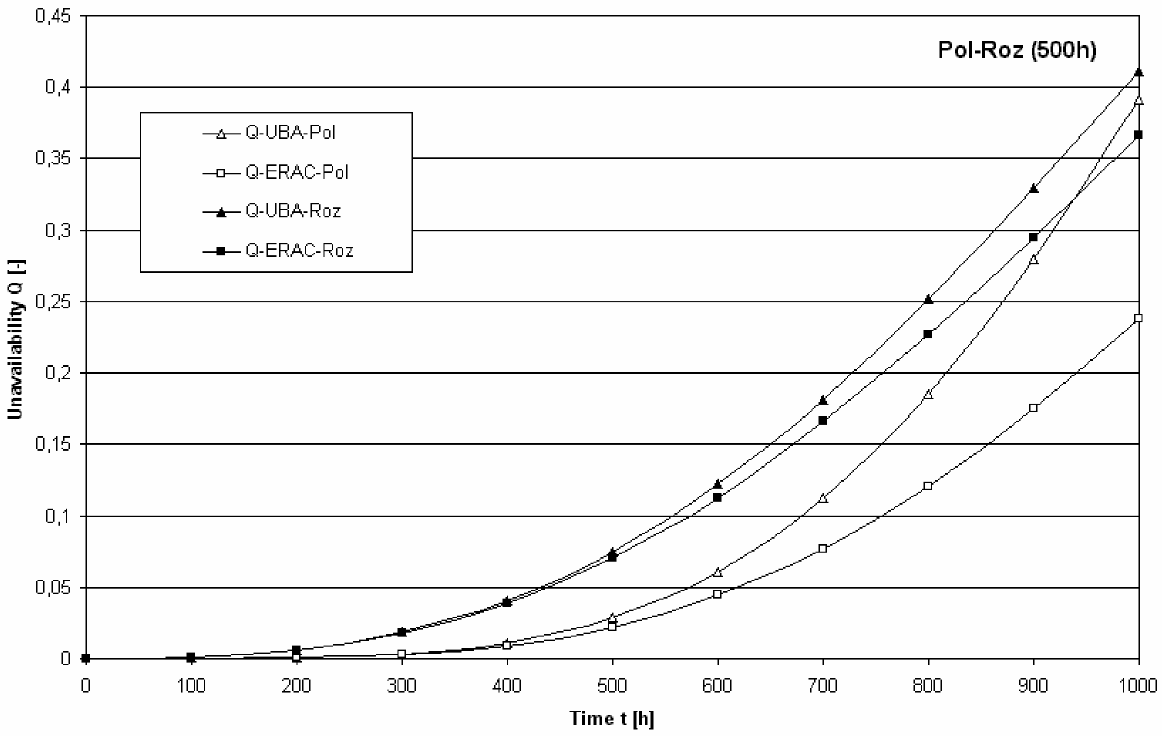

Fig. 13. The results of the effect of power plants connection for 500 hours

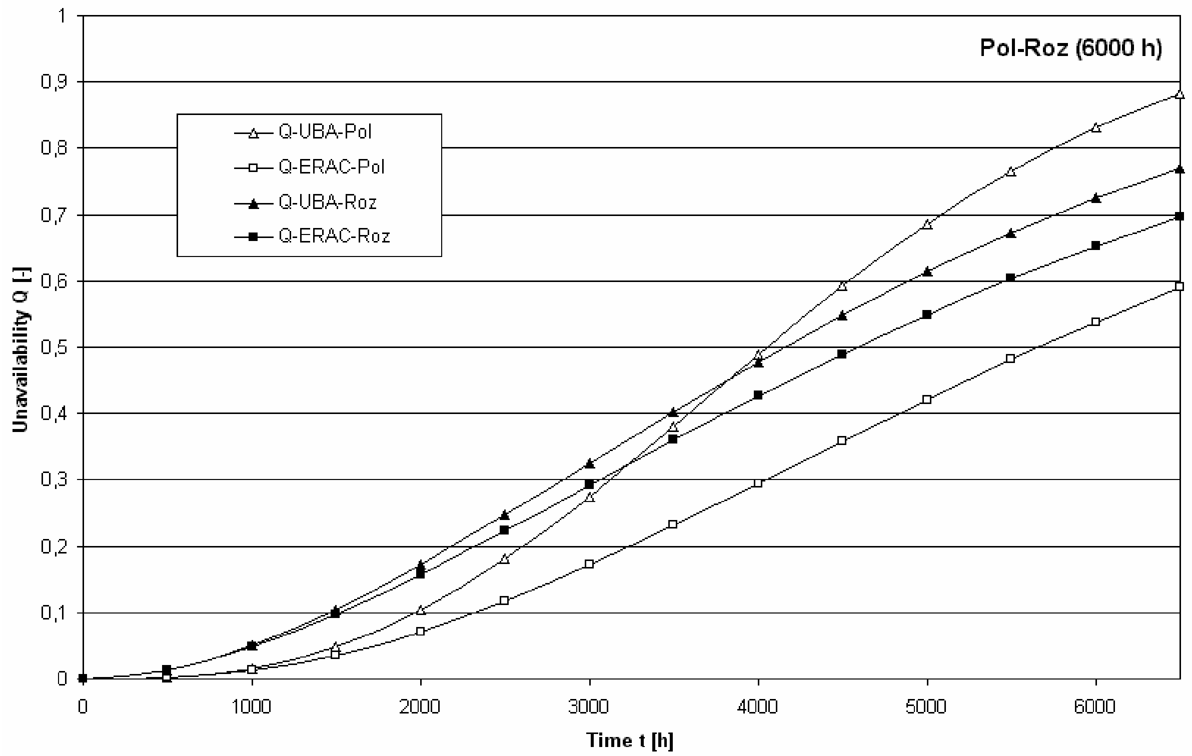

Fig. 14. The results of the effect of power plants connection for 6000 hours

4. Final conclusions

The application of time-dependent models is giving the more full description of the behaviour of system during operating. Presented methods of the simulation are giving the comfortable analysis of system unavailability characteristics of the system at selected of suitable values measures characterised events (faults in the technical system).

There is possibility of utilize the method in the proposed form (time-dependent models) for examinations of influence of redundancy for availability measures of the system and simulating failure states of elements in the moment of simulation beginning (start of observation).

In case of using data coming from the description of similar objects in the analysis, it is necessary to take individual features (one or more selected depending on kind of analysis) of the analysed object into consideration. For offshore objects it can be: hydro-meteorological conditions, the region of sailing and working, the task, which the object is executing, training of personnel etc.

Literature

1. Aven, T., *Reliability/Availability Evaluations of Coherent Systems Based on Minimal Cut Sets*, Reliability Engineering Vol. 13, 1985, p. 93 – 104.
2. Ayyub B. M., *Guidelines for Probabilistic Risk Analysis of Marine Systems*, Report CBST-97-101. University of Maryland, College Park, May 1997.
3. Barlow R. E., Proschan F., *Statistical Theory of Reliability and Life Testing*. John Wiley & Sons, New York 1972.
4. Chybowski L., *Analiza pracy systemu energetyczno-napędowego statku typu offshore z wykorzystaniem metody drzew uszkodzeń.* Materiały XXII Sympozjum Siłowni Okrętowych SymSO 2001. WTM Politechnika Szczecińska, Szczecin 2001, p. 83-88.
5. Chybowski L., *Auxiliary installations' fault tree model for operation analysis of vessel's power plant unit.* Балттехмаш – 2002, KGTU, Kaliningrad, Czerwiec 2002, p. 299-301.
6. Chybowski L, *System energetyczno-napędowy jako podstruktura systemu dynamicznego pozycjonowania jednostki oceanotechnicznej.* Materiały XXIII Sympozjum Siłowni Okrętowych, Akademia Morska, Gdynia, 2002, p. 39-44.
7. Chybowski L., Matuszak Z., *Podstawy analizy jakościowej i ilościowej metody drzewa niezdatności.* Zeszyty Naukowe nr 1 (73) Akademii Morskiej w Szczecinie, Explo-Ship 2004, Akademia Morska, Szczecin 2004, p. 129-144.
8. Chybowski L., Matuszak Z., *Symulacja niegotowości systemu siłowni okrętowej oparta na drzewie niezdatności.* Zeszyty Naukowe nr 1 (73) Akademii Morskiej w Szczecinie, Explo-Ship 2004, Akademia Morska, Szczecin 2004, p. 145-159.
9. *CARA-Fault Tree Academic ver. 4.1.* Sydvest Software. Trondheim 1999.
10. Doulliez, P., Jamoulle, J., *Transportation Networks with Random Arc Capacities*, RAIRO, 3, 1972, p. 45-60.
11. *Lungmen Units 1 & 2. Preliminary Safety Analysis Report.* TEP. General Electric. Tajwan, 2000.
12. Matuszak Z., Surma T., *Drzewo uszkodzeń i elementy algebry Boole'a jako sposób oceny niezawodności i diagnozowania instalacji siłowni okrętowej*, Materiały XVI Sesji Naukowej Okrętowców, Szczecin – Dziwnówek 1994. Wyd. Stoczni Szczecińskiej S.A., Szczecin 1994, cz. II, p. 69 – 76.

13. *OREDA. Offshore Reliability Data Handbook.* 3-rd Edition. Det Norske Veritas. Høvik.1997.

14. Vesely W. E., Goldberg F. F., Roberts N. H., Haasl D. F., *Fault Tree Handbook*, NUREG-0492. U. S. Nuclear Regulatory Commission, Government Printing Office, Washington, January 1981.

Symulacja niegotowości systemu siłowni okrętowej jednostki oceanotechnicznej wybranymi algorytmami

Słowa kluczowe: system energetyczno-napędowy statku, drzewo niezdatności,
symulacja niegotowości systemu siłowni]

Na przykładzie wybranego systemu siłowni okrętowej wielozadaniowego statku oceanotechnicznego wspomagającego eksplorację dna morskiego dokonano symulacji niegotowości tego systemu. Analizę wykonano opierając się na drzewie niezdatności dla systemu zasilania paliwem metodą aproksymacji kresu górnego i algorytmem dokładnej kalkulacji.

Simulation of unavailability of the offshore unit's power plant system with use of selected algorithms

Key words: ship power-propulsion system, fault tree,
simulation of power plant unavailability

The selected power plant system of a multi support offshore vessel exploring seabed was used for a simulation of the unavailability of the system. The analysis was performed on the basis of a fault tree for fuel supply system by the upper bound approximation and with the use of the exact calculation algorithm.

Zbigniew Matuszak
доктор технических наук, профессор

домашний адрес:
Польша (Polska), 73-100 Stargard Szczeciński, os. Zachód A13/a6

служебный адрес:
Польша (Polska), Akademia Morska, 70-500 Szczecin, ul. Waly Chrobrego 1-2

электронная почта:
zbimat@wsm.szczecin.pl

служебный телефон:
(код Польши 048, код Щецина 91) +048-91-4809414

домашний телефон: +048-91-5732728

факс: +048-91-4809575

Leszek Chybowski
Mgr. Inż., mechanik okrętowy

M.Sc. Marine Engineer

домашний адрес:
Польша (Polska), 73-100 Stargard Szczeciński, os. Zachód B18/C4

служебный адрес:
Польша (Polska), Politechnika Szczecińska, 70-310 Szczecin, al. Piastów 19

электронная почта:
leszek.chybowski@plusnet.pl

служебный телефон:
(код Польши 048, код Щецина 91) +048-91-4845717

домашний телефон: +048-91-8340706

факс: +048-91-4494346