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Ship's diesel electrical system availability modeling

Keywords

markov, diesel generators, PRA, Reliability

Abstract

One of the most critical systems for a ship operation is the diesel generator set. This is why the ship preserves four different diesel generators except the power battery packs. The paper describes the generator operation and the main failure conditions. Assuming that the failure rate of the system parts is constant the paper shows how the diesel generator system could be modelled in the context of Markov theory.

1. Introduction

The diesel generator system (DGS) is one of the most critical equipment of the ship. A failure in this system may have severe consequences human, ecological or economical. This is why it is important that the failure risk in the diesel set is estimated.

This paper analyzes the function of the DGS by describing some of the elements and different events of failures. A Markov model is used which shows the different aspects in the generator's operation in failure circumstances.

The operation of the system is continues, most of the time one generator is activated while the others operate in cold stand by. Data shows that the failure and repair rates are constant this is why Homogeneous Continues Time Markov Chains are used. The model estimates the event of an undetected failure in one of the generators [9].

The next section describes the DGS operation in general. Section three mentions possible failures in the system, while section four analyzes the Markov model of the system. The fifth section presents a numerical example on the model and the paper is completed with the conclusions.

2. Operation in the diesel generator set

The production and the distribution of electric current is carried out from diesel generator sets. The generator functions either from the diesel generator engine or from steam turbine. The turbine's axis is connected with the generator, which produces the electric current (main generator) or in other cases with suitable provision with the axis of the ship's propulsive main machine (shaft generator).

The vessel studied in this paper preserves two main machines and two more in stand by mode, in case of failure of the main machines.

Constructor's studies determine if the combination for the movement of the main generators will be carried out with diesel generator engines, with steam turbine or with shaft generator.

The distribution of the electric current from one diesel generator set in use is studied in a way to overlap the ship's needs of electric current consumption in all engines of auxiliary machinery. It should function for supporting the main machine for the propulsion of the ship, the consoles in the control rooms, the navigation equipment, the steer mechanisms and the ship's lighting. In general all the daily requirements of electric current are covered from one diesel generator set.

At the arrival in the harbor, the departure (stand-by) and the discharging for the covering of the requirements of the cargo more generators are needed. In this case two or three generators may be combined in parallel.

If the ship is in anchorage or loading state the auxiliary machinery is not operating, so the electric load is decreased and one generator is adequate for the ship's needs.

The diesel generator sets, which are not operating, are always in stand by mode so in case of failure, they replace the one operating. Besides stand by generators are activated in the event of overcharging if the needs in electric load are increased. So they function in parallel automatically or manually from the ship's electrician, or the engineer officer in duty.

The distribution of the electric current [3] from diesel generator sets is being carried out in two bus bars with voltage at 440 VOLT bar and a 220VOLT bar of electric current for an emergency purpose.

These electric current bars are located in the main switchboard. The one supplies with electric current all the main electric consumptions and also the emergency switchboard and the other bus bar supplies bowthraster and the deck machinery. The consumption of the lighting and control consoles with the suitable provision of transformers, are supplied from the main switchboard.

The emergency generators set - which is part of the ship's safety equipment when there is no electric current from the main diesel generator set - is automatically activated and distributes electric current through the emergency switchboard in some particular machinery as to secure the ship's safe operation in a case of an emergency. That machinery is the below mentioned:

- steering gear,
- emergency air compressor,
- E/R vent fan,
- fire pump,
- steering gear fan and fire pump room fan,
- the foam liquid pump,
- the pumps G/E MDO flushing/DO booster pump,
- Radars,
- ship's radio equipment,
- Gyro/Auto pilot system,
- satellite communication system,
- electric whistle,
- navigation / intercommunication system,
- E/R control console,
- emergency lighting
- the navigation light.

3. Possible failures in the diesel generator set

In system's total failure (main and emergency) a provision of batteries may support the bridge control console, the engine room console, the radio equipment and the emergency lighting system, so as to ensure the crew safety and the communication center on shore.

The reasons [5] for the starting of a diesel generator set which is in a stand by mode are mentioned below:

a) No electric current is detected in the main bus bars of the main switchboard.
b) Low voltage of electric current in the main bus bars.
c) High voltage of electric current in the main bus bars.
d) Low frequency of electric current in the switchboard.
e) Sudden reservation in the diesel generator set which functions.
f) Overcharging of the diesel generator set which functions and supplies electric current to the ship.

The diesel generator set which is in stand by mode will start after the below mentioned situations:

Concerning situations (a) or (e) the diesel generator set automatically synchronizes and shares the load consumption's needs.

In situations (b), (c) or (d) the diesel generator set which is in stand by mode starts, synchronizes and undertakes the load consumption's needs before the diesel generator set which was operating stops.

For the functional situation (f) where the load needs are increased the diesel generator set which is in a stand by mode starts automatically, synchronizes and share the load's needs with the diesel generator set which was already operating and they simultaneously operate together.

4. Markov analysis

Markov process theory belongs in stochastic science. It is possible to compute the dynamics sequentially in terms of the current state, the state transition rule (differential equation), and the time increment in appropriate units.

The various system states are defined by the states of the components comprising the system. By the state-space method the components are not restricted to having only two possible states. The components may have a number of different states such as functioning, derated, standby, completely failed, and under maintenance. The various failure modes may also be defined as states.

The transitions between the states are caused by various mechanisms and activities such as failures, repairs, replacements, and switching operations. The state-space method is not restricted to only two possible states of the components. The method can be used to model rather complicated repair and switching strategies. Common cause failures may also be modelled by the state-space method.

The use of the Markov techniques within the scope of FSA intends to adopt realistic, detailed probabilistic models for further carrying out of sensitivity analysis owing to these techniques:

- The repairs of the components can be taken into account.
- The reliability and availability computations can be carried out.
- The normal/standby operating sequences and, more generally, all the changes in the configuration of the system under study can be considered.
- Multi-step system operating sequences can be taken into account.

In addition, the sequential computation of a graph allows the visualization of the progress of alternate failures and repairs as time passes, leading to system failure, and the computation of the probability of measures being taken before the complete loss of the system.

On the other hand, using Markov techniques is uneasy due to the complexity of the graphs to be processed in case of complex systems. The techniques applied for state aggregation, which aim at the minimization of the number of states or sequential computations in order to build simplify the graph, generally permit the problem to be reduced to a reasonable size. The association of costs with each state allows the access to performability modelling.

In *Figure 1* the system is modeled by Homogeneous Continuous Time Markov Chain [9]. According to experts we accept the following assumptions:

- If one generator fails, the expert checks the rest of them.
- If a main generator fails, the probability of failure in a stand by machine is very close to zero.

Below a description of the model is presented:

State 1: The ship is in harbour at a discharging phase and uses two generators, the rest of them are in stand by mode.

State 2: One of the main generators fail and the automation is damaged too, so the stand by generator does not start automatically. The gen/tor launches manually in time "t_{man}"

State 3: Two gen/tors operate, one in repair.

State 4: Same as in State 2 but the Automation works so after time "t_{aut}" the second gen/tor takes on. Variable "γ" is the probability that the automation works. ("1-γ" in case of failure of the automation)

State 5: Same as in State 3

State 6: One of the SB gen/tors fails but the failure is undetected.

State 7: Two gen/tors fail one main and one sb, but the automation operates so in short time the system passes in State 8

State 8: Two gen/tors in failure, but the ship is supported effectively. Two devices are in repair mode.

State 9: Two gen/tors in failure, the automation fails too, the last sb generator has to start manually.

State 10: The ship is supported effectively.

State 11: Since the failure in State 6 is undetected the second sb generator might be in failure too.

State 12: Rare event but it could happen, a third generator to fail. In this case one of the mains is repaired, and the model passes to State 13.

State 13: Two gen/tors in failure, the system remains in this state until the repair is completed then it passes in safe state 1.

5. Numerical example

The model was tested with data given by Greek maritime company. The data concern common failures in the generators and the mean time of repair.

Table 1. Failures in the generator.

	Type of damage	Inter Occurence Time (days)	Restoration time (hours)
(1)	Fuel oil filters	20	1,5
(2)	Oil filters	20	1,5
(3)	Air filters	20	1,5
(4)	Water filters	30	1,5
(5)	Fuel Injectors	60	1,5
(6)	Leaking of gasket	90	1,5
(7)	Piping system	60	1,5
(8)	Water pump	60	3
(9)	Fuel pump	30	3
(10)	Fuel injector	180	3
(11)	Dirty water cooler	60	3
(12)	Dirty oil cooler	60	3
(13)	Cover gasket damage	365	3
(14)	Exhaust inlet valve	365	7

(15)	Cracking of cylinder heads	240	7
(16)	Piston ring damage	365	7
(17)	Turbo charger	365	7

Based on the data of *Table 1* the failure rate "λ" and "μ_{op}" are calculated. The rest of the rates, probabilities and times of the model are given approximately by the machine experts.

By solving the linear system (1) which is following the steady states of the system are given in *Table 2.*

$$\Pi \cdot \mathbf{Q} = 0$$
$$\sum_{\mathbf{i}=1}^{\mathbf{n}} \pi_{\mathbf{i}} = 1 \qquad (1)$$

Data in the following table show the availability probability of the system. In states "two", "four", "seven", "ten" and "twelve" the generators can not support the unloading procedure of the cargo. So the availability of the system is 99,04 %. The mean time of repair is about two hours, a very significant delay for a ship at an unloading phase.
According to data given from Greek maritime company the mean cost of a 500 TEU container for every hour of delay is \$ 125. The mean cost for the terminal is \$ 140. If the unloading speed per hour is 6,26 containers (according to Piraeus Port) the mean cost is \$ 1,658.9.

6. Conclusion

Homogeneous continuous time Markov chain was used as a risk assessment methodology in the failure estimation for a ship's generator set. The modelling of the system shows that the general behaviour of the generators set can be recorded, taking into account the failures and repairs of the whole system. This can not be done with the usual methodologies applied in Formal Safety Assessment studies.
The next step in the paper, is to calculate the performability indicators combining unavailability and mean cost.

Table 2. Steady states.

State	Steady states
1	0,3616
2	2,37E-07
3	3,89E-05
4	0,0003
5	0,5058
6	0,0657
7	0,0001
8	0,0460
9	4,60E-05
10	4,31E-08
11	0,0066
12	0,0092
13	0,0046

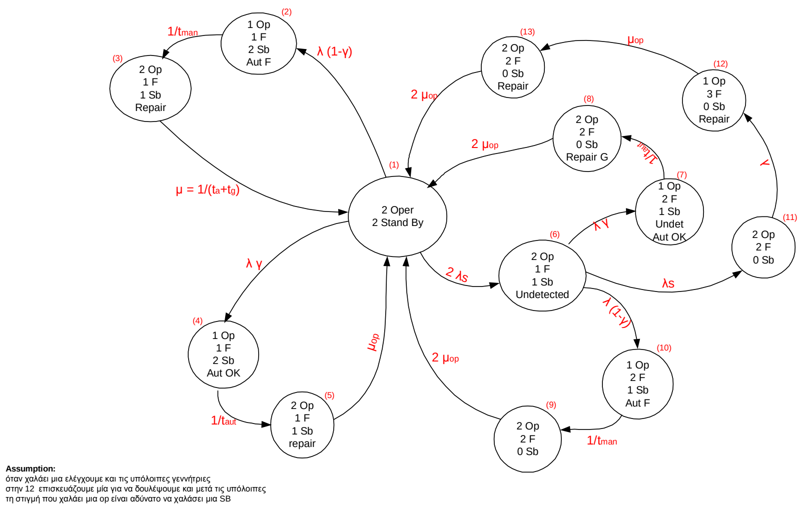

Figure 1: Markov model for diesel generators system.

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