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Marine Auxiliary Engine System Reliability Assessment by Fault Tree Analysis: A Case of MV Victoria Genset in Tanzania

Humphrey Swalle[1], Dr. Werneld Ngongi[1] and Geophrey Damson[2]
[1]Department of Marine Engineering, Dar es salaam Maritime Institute, P.O. Box 6727, 1/19 Sokoine Drive, Dar es salaam
[2] Department of Research, Tanzania Fisheries Research Institute, Dsm, 9750 Tanzania.
Correspondence email; humphreyswalle@gmail.com
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Abstract

The dependability of marine auxiliary machinery, in particular Marine Diesel Generators (MDGs), which are important for supporting critical ship activities, is critical to ensuring the safety and effectiveness of maritime operations. These generators have the potential to seriously affect ship operations, crew safety, and the environment. The purpose of this study is to assess the MDGs' reliability on board the MV Victoria, where rising failure rates have been noted over time as a result of component wear and poor maintenance. To evaluate the interdependencies and failure probabilities of MDG components, fault tree analysis, or FTA, was utilized. According to the results, mechanical failures are the most serious since they occur at far higher rates than electrical failures, which cause reliability to deteriorate more quickly over time. These findings highlight the requirement. These findings highlight the need for focused maintenance plans that give mechanical systems first priority in order to improve the overall dependability of maritime auxiliary machinery.

Keyword: *Marine Diesel Generator; Reliability; Fault Tree Analysis; Mechanical Failure*

Introduction

In the maritime sector, maintaining the safety, effectiveness, and continuous functionality of vessels during their journeys depends critically on the marine auxiliary machinery's dependable operation(Kim et al., 2022). The marine diesel generator (MDG) is one of these vital parts that is particularly important for supplying vital electrical power for different onboard systems and equipment. Because of its crucial purpose, any malfunction or failure of the MDG can have a major effect on the environmental integrity, crew safety, and vessel operations(Văn Ta et al., 2017). Therefore, in order to detect possible failure modes, analyze risks, and put into practice efficient maintenance plans in order to save downtime and guarantee operational readiness, thorough reliability assessment approaches are crucial.

Ensuring the safety and efficiency of maritime operations is critically dependent on the reliability of marine auxiliary machinery. Marine diesel generators (MDGs), vital for supporting main propulsion engines and other essential ship functions, frequently experience failures despite their importance (Dong et al., 2015). These failures can negatively affect the environment, crew safety,

and ship integrity, raising significant concerns about the dependability of such equipment (Anantharaman et al., 2015). The absence of reliable evaluation techniques for these specific challenges hinders effective risk management and maintenance planning within the shipping industry (Cholda, 2014). Thus, developing precise and reliable methods for evaluating the dependability of marine auxiliary machinery is crucial to minimizing malfunctions, reducing maintenance costs, and enhancing overall maritime safety.
The focus of this study is on evaluating the reliability of maritime auxiliary equipment, particularly the marine diesel generator aboard the MV Victoria. Despite their design to withstand harsh maritime conditions, MDGs often face increased failure rates over time due to factors like component wear and suboptimal maintenance (Lazakis et al., 2019).. A systematic approach, such as fault tree analysis (FTA), is necessary to address the complexity and interdependence of MDG components and to accurately assess failure probabilities given variable operating conditions. This research aims to address the gap in literature regarding marine auxiliary equipment reliability by applying FTA to the MV Victoria's MDG, offering insights into failure mechanisms and contributing to better maintenance practices and risk management strategies.

A summary of a few comparable techniques may be found in Section 2. Next, a brief methodology for certain FTA studies for the marine propulsion system and results of the marine power plant system as a whole is given in section 3. Lastly, part 4 presents a discussion of an FTA model used in the study of the marine propulsion system.

2. Methodology

The research was conducted at Marine Service Company Limited (MSCL) in the Department of Ferry, at Mwanza region in Tanzania. The generator logbook and manual were used as material in this study. A case study involved one generator of MV. Victoria's out two MDGs are observed and reviewed. The data was collected from the successful trial completion and subjected to Fault Tree Analysis using the PTC windchill solutions. Using the logic gates in the PTC Windchill Solutions, the entire fault tree analysis for auxiliary machinery reliability especially MDG was done and studied. From the results, the unreliability and unavailability of the fault tree are used to calculate the reliability and availability of marine auxiliary machinery.

3. Results and Discussion

The auxiliary generator's fault tree graphic shows the intricate relationships between subsystems and how they interact with one another. Calculating the chance of failure at each gate took four years of historical data using PTC windchill. The investigation showed incredibly low reliability, particularly for MDG 1, as a result of maintenance problems including malfunctioning injector pumps.

3.1 The Construction of Fault Tree

The fault tree diagram of the auxiliary generator is shown in Figure 1A. As the system and component are connected in series by OR gate was used to failure type to top event. In what follows the fault tree diagrams of individual sub-systems are constructed. The FT shown in Figure show the complexity of interaction of between different subsystems in the investigated system. Figure

4.1 shows the FT of bearing, rotor or stator failure, electrical, air, Fuel, and lubrication respectively. The Fault tree diagram is constructed by dividing the system into parts.
dividing the system into parts.

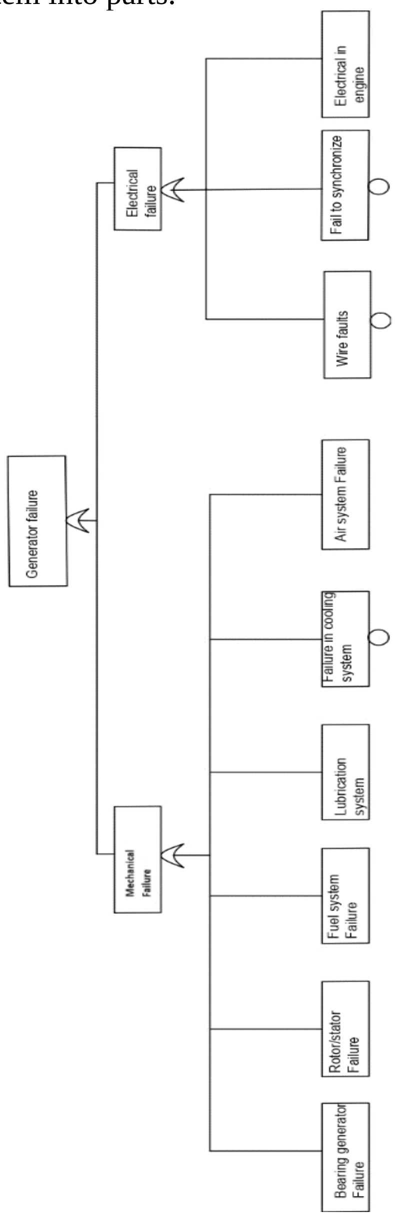

***Figure 4. 1*: Fault Tree Diagram of Generator**

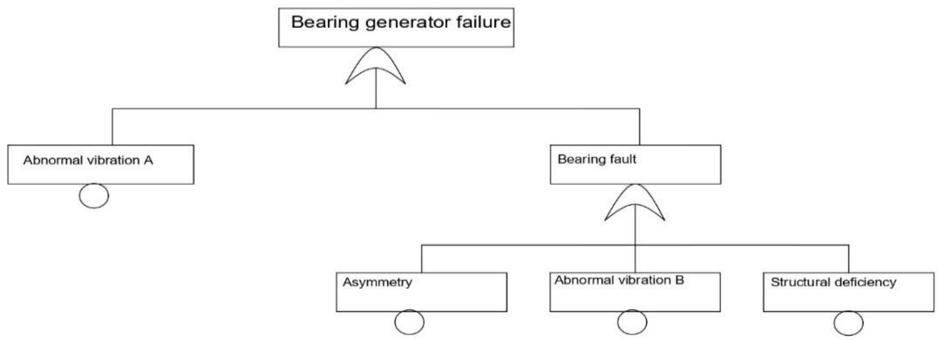

***Figure 4. 2*: fault tree Diagram of generator**

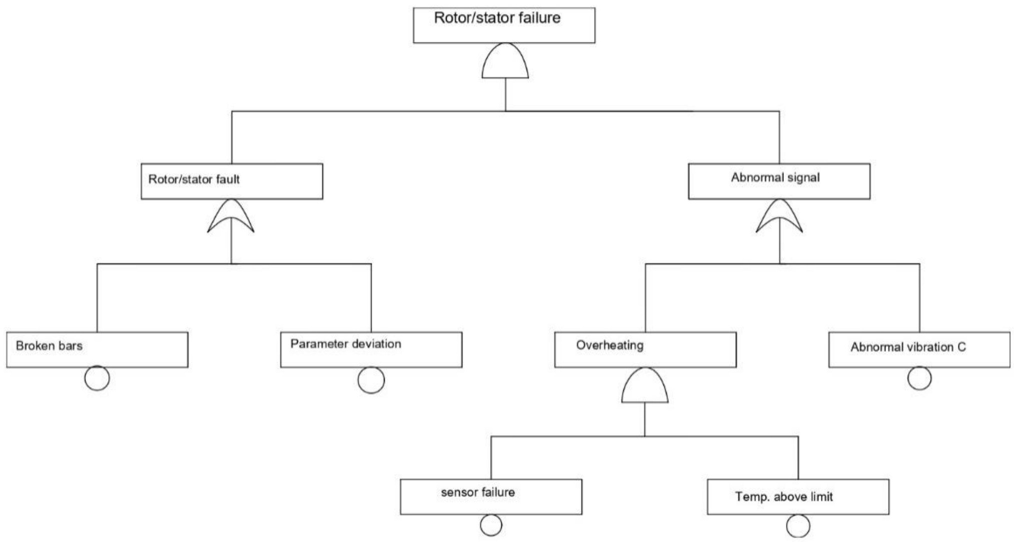

***Figure 4. 3*: fault tree Diagram of stator**

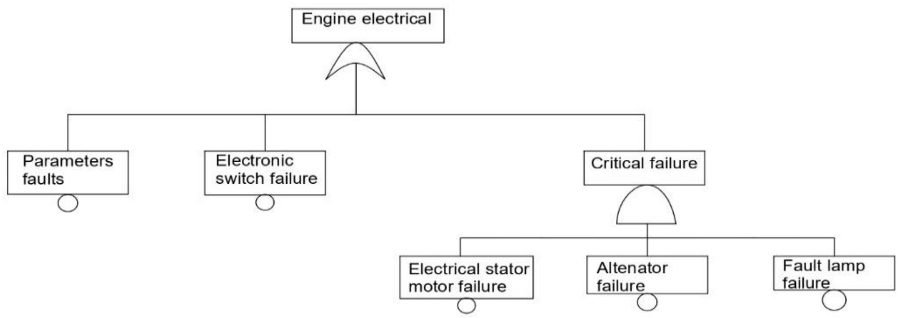

***Figure 4. 4*: Fault tree diagram of electrical**

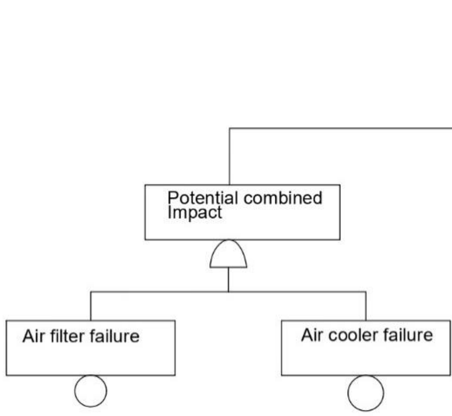

Figure 4. *5*: **Fault tree diagram of air filter**

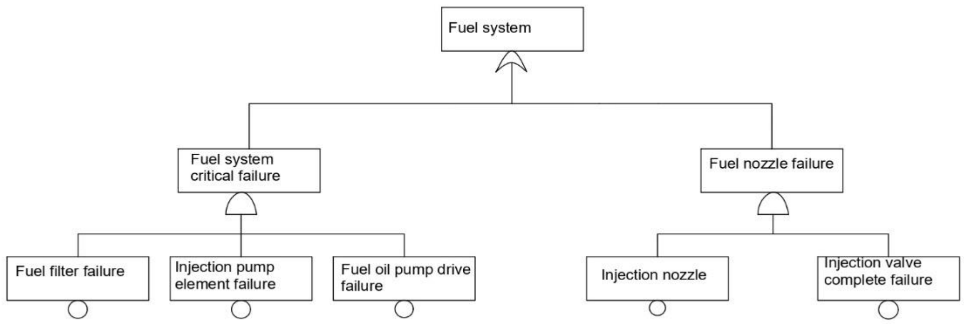

Figure 4. 6: **Fault tree diagram of fuel**

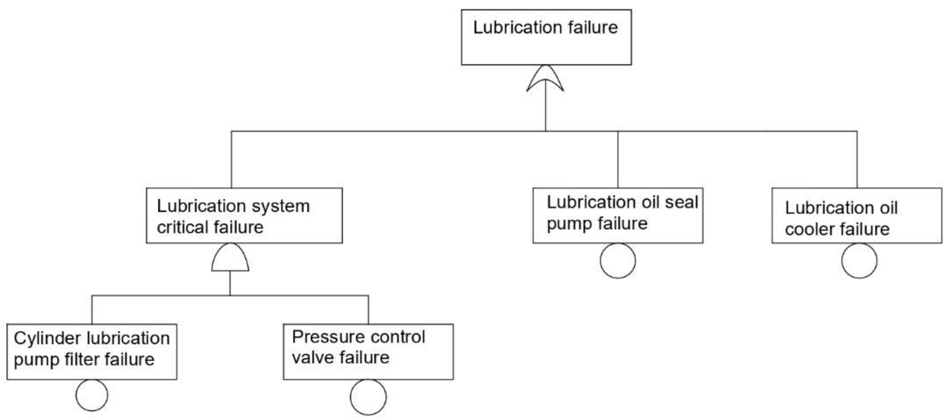

Figure 4. 7: **Fault tree diagram of lubrication**

3.2 Quantitative FTA of MDG3

From table 4.6 below, the reliability analysis for Generator 03 spans 0 to 8760 operation hours (1 year), focusing on two main failure types: mechanical and electrical failures. The failure rates for these types are 0.0412 and 0.0078, respectively. Reliability, calculated using $R(t)=e^{-\lambda t,}$, shows an exponential decrease over time for both failure types, with mechanical failures declining more rapidly due to their higher failure rate.

Mechanical failures for Generator 03 begin with 100% reliability at hour 0 but experience a rapid decline over time. This is attributed to the higher failure rate (λ=0.0412) which significantly reduces reliability within the one-year operational period. By the end of 8760 hours, the reliability of mechanical components is considerably lower, indicating a critical need for frequent maintenance or replacement to ensure the generator's overall reliability.

In contrast, electrical failures in Generator 03 start with the same 100% reliability at hour 0 but decline at a slower rate. With a lower failure rate (λ=0.0078) electrical components maintain higher reliability over the same period. Although still important, electrical failures pose a lesser risk to the generator's overall reliability within the one-year timeframe, making them a secondary concern compared to mechanical failures.

In conclusion, the reliability table for Generator 03 highlight that mechanical failure is the most common and critical failure mode affecting its reliability. The higher failure rate and faster decline in reliability for mechanical components suggest that maintenance strategies should prioritize addressing these failures to maintain optimal performance. Electrical failures, while still significant, are less likely to occur within the same period, making them a lesser concern in comparison to mechanical failures.

Table 4. 6: **Quantitative FTA of MDG3**

Failure Type	**3 resolutions**	**2 resolutions**	**2 resolutions**	**Top event**
Fuel filter failure 0.009				
Fuel feed pump failure 0.0001	Fuel system critical failure 0.0099			
Flow limiting valve failure 0.0004				
Fuel pumps. failure 0.0001				
Fuel oil pump drive failure 0.0003				
		fuel system 0.0121		
Injection pump element failure 0.0004				
Injection valve nozzle failure 0.0002	Fuel nozzle failure 0.0007			
Injection valve complete failure 0.0001				
Ignition system failure 0.0001				
Faulty signal/indication/alarm failure 0.0001	other fuel 0.0015			
Gauges failure 0.0001				

Other pumps failure 0.0012				
Cylinder lubricating pump filter failure 0.0003				
Pressure control valve failure 0.0001	lubrication system critical failure 0.0007		Mechanical failure 0.0412	
Pre-lubrication systems failure 0				
Cylinder lubricating pump failure 0.0003		lubrication failure 0.0035		
	Lubricating oil seal pump failure 0.0015			
	Lubricating oil cooler failure 0.0013			
heat sleeves fail 0.0006				
Air filter failure 0.003				
Air compressors failure 0	potential combined impact 0.0069			
Air cylinders failure 0.0003				
Air cooler failure 0.003				
	Instrument pressure air piping failure 0.0003	Air system failure 0.0077		
	Turbo charge failure 0.0005			

		Coolant level switches failure 0		
		cooling system failures 0.0014		Generator failure 0.049
Structural deficiency 0.002				
Abnormal vibration A 0.001	Bearing faults 0.0035			
Asymmetry 0.0005		bearing generator failure 0.0047		
	Abnormal vibrations 0.0012			
	Belts failure 0.0010			
	Clutches failure 0.0018	Transmission 0.0065		
	Torque converters failure 0.0025			
	Drive plates failure 0.0012			
Broken bars 0.0030				
parameter deviation 0.0015	rotor/stator faults 0.0035			
		rotor /stator failure 0.0053		
Overheating 0.0018	abnormal signal 0.0018			
Abnormal vibration C 0				

		wire faults 0		
Electric starting motor failure 0.0015				
Alternator’s failure 0.0020	critical failure 0.0045			
Fault lamps failure 0.0010				
Engine protection controls failure 0.0018	Electronic switches failure 0.0018			
		Electrical in engine 0.0078	electrical failure 0.0078	
	Parameters faults 0.0015			
		fall to synchronize 0		

4. Conclusion

The FTA analysis, as discussed previously, is proposed for assessing the reliability of Marine Diesel Generators (MDG) over a period of time. However, it is important to note that this method cannot fully reflect the entire life cycle of the system. On the other hand, it remains a suitable approach for evaluating the reliability of Marine Auxiliary Machinery.

Failure analysis of Marine Auxiliary Machinery is typically conducted using various reliability analysis methods, spanning from the design stage to the operational stage. These analyses are crucial for achieving a high level of reliability in Marine Auxiliary Machinery. A key challenge in this process is determining the exact failure probability of basic components (basic events), which is often difficult for engineers to ascertain. The failure probability of these components and the overall reliability of the Marine Auxiliary Machinery are influenced by factors such as ship mobility, loading conditions, and weather. The theoretical data obtained from comprehensive reliability analysis can guide the development of methods or countermeasures to enhance the reliability, safety, and efficiency of Marine Auxiliary Machinery, which is crucial for the successful completion of a ship's missions.

Additionally, the probability of failure of the component with the highest risk will have a significant impact on the overall system. It is also important to consider the relationships among the various components within the Marine Auxiliary Machinery to ensure a holistic understanding of the system's reliability.

The research identified mechanical failures as the dominant failure mode affecting generator reliability, with significantly higher failure rates compared to electrical failures. Across Generator, mechanical failures were consistently observed to cause faster declines in reliability over time, highlighting their critical impact on overall machinery performance. This finding underscores the importance of focusing maintenance efforts on mechanical systems to preserve the reliability of the generators.

Based on the findings from the assessment of the Marine Diesel Generators (MDG) aboard MV Victoria, it is recommended that Marine Services Company Limited prioritize several key actions to enhance the reliability and performance of the vessel's auxiliary machinery. One of the most critical areas identified in the research is the prevalence of mechanical failures, which have been shown to be the dominant failure mode affecting generator reliability. These mechanical failures exhibit significantly higher failure rates compared to electrical failures, leading to faster declines in reliability over operational periods. Therefore, focusing maintenance efforts specifically on mechanical systems will be essential in mitigating the adverse impact these failures have on overall machinery performance.

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