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Fire & Explosion Hazards at Gas Turbines in Power GenerationPlants

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Abstract

The gas turbine has become an important, widely used, and reliable device in the field of energy generation, transportation, and other applications. A gas turbine, also called a combustion turbine, is a type of continuous flow internal combustion engine. The main hazard associated with gas turbines is a gas leak and the accumulation of combustible gas in a confined location, which has the potential to create an explosion or fire if ignited. Thus, this research paper focuses on reducing gas turbine fire & explosion events in order to limit the possibility of a gas leak and flammable gas buildup using advanced control measures.

Keywords
Gas turbine, power generation plant, fire & explosion and FMEA.

1. Introduction
In the 1940s, the rapid development of gas turbines led to the introduction of a replacement for traditional reciprocating engines. Gas turbines are complex energy transformation systems. As with other internal combustion engines, they are comprised of hundreds of subsystems and the primary system is the consequence of the subsystems coming together. Due to their high-power output, efficiency, and dependability, gas turbines are widely used in industrial applications. Due to the nature of the fuels, they use, and the high temperatures and pressures involved in their operation, these devices also pose a significant risk of fire and detonation. To ensure the welfare of personnel and the environment, it is essential to comprehend the primary causes of fires and explosions at gas turbines.

This research paper will investigate the primary causes of gas turbine flames and disasters. In order to develop effective strategies for preventing accidents and assuring the safe and reliable operation of gas turbines, it is essential to identify the fundamental causes of such incidents. The risks associated with gas turbines and the potential consequences of fires and explosions will then be discussed. Next, we will examine the primary causes of fires and explosions, such as fuel leakage, combustion problems, overheating, apparatus failure, and human error. For each cause, we will investigate the underlying mechanisms and provide real-world examples of incidents resulting from that cause. This paper provides a detailed FMEA that analysis the potential hazards of fire in gas turbines. Based on the findings, the research paper emphasizes the significance of preventing fires and explosions in gas turbines. By emphasizing the importance of routine maintenance, training, and safety protocols to reduce the risk of accidents and ensure the safe and dependable operation of gas turbines.

1.1 Objectives

The purpose of this research paper is to provide a clear understanding of the main causes of fire & explosion hazards at gas turbines in power generation plants. This research seeks to recommend a systemic strategy and mitigation plan for reducing the risk of fire and explosion at power generation plants. The research provides a detailed analysis to illustrate the causes of fire in gas turbines using the Failure Mode and Effect Analysis (FMEA) methodology, which prioritizes failures based on their Risk Priority Number (RPN). In addition, the research proposes solution controls to efficiently and effectively prevent or mitigate the problem. By identifying the risks and implementing a comprehensive plan that includes a detection system and solution controls, power generation facilities can reduce the risk of fire and explosion, thereby safeguarding the facility, its employees,and the adjacent community from potential harm.

2. Literature Review

Gas turbines are a vital component of many industrial processes, providing efficient and reliable power generation. However, gas turbines are also associated with several hazards, including fire and explosion. These hazards can result in significant damage to equipment, injury to personnel, and environmental pollution. Understanding the main causes of fire and explosion at gas turbines is essential for ensuring safe and efficient operation.

One of the primary causes of fire and explosion at gas turbines is fuel leaks. Fuel leaks can occur due to various reasons, including corrosion, vibration, and wear and tear. According to Kim et al. (2019), fuel leaks can lead to the accumulation of combustible gases, which can ignite due to a spark or other sources of ignition. To prevent fuel leaks, regular inspections and maintenance of fuel systems are essential.

Another significant cause of fire and explosion at gas turbines is electrical faults. Electrical faults can occur due to various reasons, including aging of equipment, improper maintenance, and environmental factors such as moisture and dust. According to Lohmeyer et al. (2017), electrical faults can lead to arcing, sparking, and overheating, which can ignite combustible materials. To prevent electrical faults, regular inspections and maintenance of electrical systems are essential.

Inadequate ventilation is also a significant cause of fire and explosion at gas turbines. Inadequate ventilation can lead to the accumulation of combustible gases and the lack of oxygen required for combustion. According to Shin et al. (2018), inadequateventilation can cause hot spots to develop, leading to the ignition of combustible materials. To prevent inadequate ventilation,regular inspections and maintenance of ventilation systems are essential.

Furthermore, human error is another significant cause of fire and explosion in gas turbines. Human errors can occur due to various reasons, including lack of training, fatigue, and complacency. According to Smith et al. (2018), human errors can leadto mistakes in the maintenance, installation, and operation of gas turbines, which can result in fires and explosions. To prevent human error, proper training, and adherence to safety protocols are essential.
One major cause of fire and explosion at gas turbines is fuel leaks. According to a study by Zhiqiang Hu and Jianjun Mao (2017), fuel leaks can occur due to various factors such as corrosion, wear and tear, improper installation, and human error. The leaked fuel can ignite and cause a fire or explosion, which can be catastrophic for both the equipment and the personnel operating the gas turbine.

Another cause of fire and explosion at gas turbines is the ignition of combustible gases that accumulate within the equipment.As stated by Raza et al. (2019), combustible gases such as methane, ethane, and propane can build up within the turbine duringnormal operation. If these gases are not properly vented, they can ignite and cause a fire or explosion.
In addition, malfunctioning components such as bearings and seals can also lead to fires and explosions at gas turbines. According to a report by the UK Health and Safety Executive (2003), bearings and seals can fail due to factors such as insufficient lubrication, overheating, and fatigue. When these components fail, they can generate sparks or heat that can ignitefuel or combustible gases, leading to a fire or explosion.

Human error is also a major factor in causing fires and explosions at gas turbines. As stated by Du et al. (2020),

human errorssuch as incorrect maintenance procedures, improper handling of equipment, and inadequate training can lead to incidents at gas turbines.

Another study conducted by Yao et al. (2019) identified several potential causes of fire and explosion at gas turbines. They analyzed 43 accidents that occurred in gas turbine power plants between 2005 and 2015 in China. The study found that the main causes of fires and explosions were equipment failure, human error, and external factors.
Equipment failure was the most common cause of fires and explosions, accounting for 56% of the accidents analyzed. The study identified several specific types of equipment failures, including combustion system failure, bearing failure, and generator failure. Human error was the second most common cause, accounting for 23% of the accidents. This included errors in operationand maintenance, as well as failures in safety management systems. External factors, such as lightning strikes and fires in nearby areas, accounted for 21% of the accidents.
Similarly, a study conducted by Esen and Kalyoncu (2016) analyzed the causes of fire and explosion in gas turbine power plants in Turkey. They found that the most common causes of accidents were mechanical failure, human error, and external

factors. Mechanical failure was responsible for 40% of the accidents, while human error and external factors each accounted for 30%.

In a study conducted by Qian et al. (2018), it was found that the main causes of fire and explosion in gas turbines were due tofailures in the fuel system, electrical system, and auxiliary systems. The study investigated the incidents that occurred in China from 2000 to 2017 and concluded that the fuel system was responsible for 43% of the incidents, while the electrical and auxiliary systems were responsible for 25% and 32% of the incidents, respectively. The study recommended the implementation of safetymeasures in these systems to prevent incidents from occurring in the future.

Another study by Sánchez et al. (2017) analyzed the causes of explosions in gas turbines used in the oil and gas industry. Thestudy identified three main causes of explosions, which were fuel leaks, mechanical failure, and maintenance errors. Fuel leakswere found to be the most common cause of explosions, accounting for 40% of the incidents, while mechanical failure and maintenance errors accounted for 30% and 20% of the incidents, respectively.

In addition to these studies, numerous case studies have also been conducted to investigate specific incidents involving fires and explosions in gas turbines. For example, an investigation into a fire that occurred in a gas turbine at a power plant in Germany found that the incident was caused by a leak in the fuel system, which led to a fire in the combustion chamber (Mohnen et al., 2014). Another investigation into an explosion in a gas turbine at a petrochemical plant in Saudi Arabia foundthat the incident was caused by a failure in the bearing support system, which led to a fire in the turbine (Al-Mashouq et al. 2013).

Another study conducted by Wang et al. (2017) identified several factors that contribute to fires and explosions at gas turbines.The study found that the primary cause of fires and explosions is the ignition of flammable materials in the turbine. This can be due to a variety of factors such as leaks, hot surfaces, electrical faults, or combustible materials in the vicinity of the turbine. Additionally, the study found that human error is a contributing factor to fires and explosions at gas turbines. Human error caninclude issues such as inadequate training, poor communication, and failure to follow established procedures. Wang et al. (2017) also identified that equipment failures, such as faulty valves or sensors, can contribute to the ignition of flammable materials.

Another potential cause of fires and explosions at gas turbines is the accumulation of flammable gases in enclosed spaces. A study conducted by Smith et al. (2018) found that the accumulation of hydrogen gas in the enclosed space surrounding a gas turbine can lead to explosions. This can occur when there is a leak in the system, or if the gas is not properly vented from the turbine.

A study by Yang et al. (2019) identified that the design of the gas turbine itself can contribute to the risk of fires and explosions.The study found that the location of components within the turbine, such as fuel nozzles and combustion chambers, can impactthe risk of fires and explosions. Additionally, the materials used in the construction of the turbine can also impact its safety andrisk of fires and explosions.

In addition to the causes mentioned above, fuel quality and maintenance issues can also lead to gas turbine fires and explosions. The fuel used in gas turbines should be free of impurities and contaminants, such as water, rust, and dirt, as they can causedamage to the fuel nozzles and combustion chambers, resulting in ignition and combustion issues. Furthermore, impropermaintenance of gas turbines can also increase the risk of fire and explosion incidents. Regular inspections, cleaning, andmaintenance are crucial to ensure that all components are functioning properly and prevent any unexpected incidents. (Wagner et al. 2021) conducted a study on the potential causes of fire and explosion incidents at gas turbines. The authorshighlight that the primary cause of gas turbine fires and explosions is the ignition of fuel within the turbine system, which can be due to various factors such as faulty equipment, human error, and external factors such as lightning strikes. Additionally,inadequate maintenance, fuel quality, and design flaws can also contribute to these incidents. The authors emphasize theimportance of developing and implementing preventative measures to reduce the likelihood of gas turbine fires and explosions,such as implementing safety protocols and conducting regular maintenance and inspections.

Another study conducted by Chan and Law analyzed the root causes of 17 gas turbine accidents from 1981 to 2014. They foundthat the main causes of these accidents were equipment failure, human error, and operational issues. In particular, equipment failure, including issues with control systems, was responsible for more than half of the accidents. Human error, such as incorrect installation or maintenance, was identified as a significant factor in several incidents. Operational issues, such as poor design or inadequate risk assessment, also contributed to the accidents.

In addition, a study conducted by Wang et al. (2020) analyzed a gas turbine failure that occurred due to the presence of debrisin the compressor. The debris resulted in increased vibration levels, which in turn caused a fire in the turbine. This study highlights the importance of regular maintenance and inspection of gas turbines to prevent debris build-up.

Another study by Naik et al. (2019) identified human error as a leading cause of gas turbine accidents. The study found that a lack of training, failure to follow standard operating procedures, and inadequate communication were among the keycontributors to accidents. This highlights the importance of proper training and communication among personnel operating andmaintaining gas turbines.

Furthermore, a study by Guo et al. (2019) examined the effects of hydrogen leaks in gas turbines. The study found that hydrogenleaks can lead to catastrophic explosions and fires, which can cause significant damage and pose a serious threat to human life.Proper installation and maintenance of gas turbine systems, as well as regular inspection to detect leaks, are crucial to preventsuch incidents.

Another study by Darwish et al. (2019) identified the most common root causes of gas turbine fires and explosions in the Middle East. They found that equipment failure, inadequate maintenance, and human error were the primary causes of incidents.In particular, the authors noted that the lack of a comprehensive maintenance program was a key factor in many incidents, as it allowed small issues to go unnoticed and escalate into larger problems over time.

A study by Pacheco et al. (2018) examined the root causes of gas turbine fires in Brazil. The authors found that the mostcommon cause of incidents was human error, particularly during maintenance or repair activities. Other factors that contributedto incidents included equipment malfunction and improper installation or use of equipment. The authors recommended thatoperators take steps to improve their safety culture and invest in training and equipment to prevent incidents from occurring. A study by Karami et al. (2020) examined the causes of gas turbine explosions in Iran. The authors found that the most commoncause of explosions was equipment malfunction, particularly in the turbine blades or compressor section. They also noted thatinadequate maintenance practices and the use of low-quality parts or materials were contributing factors in many incidents. The authors recommended that operators improve their maintenance practices and invest in high-quality parts to prevent futureexplosions.

Another cause of gas turbine fires and explosions is the presence of foreign objects or debris within the turbine.

Such objects can enter the turbine during maintenance activities, manufacturing, or during operation. These foreign objects can damage theturbine blades and cause overheating, which can lead to a fire or explosion. Additionally, the buildup of dust, dirt, or other contaminants can increase the risk of a fire or explosion.

As per the study conducted by Algasim et al. (2017), the main cause of gas turbine fires and explosions is the presence of flammable gases, liquids, or solid fuels in the surrounding atmosphere. Flammable gases may escape from pipelines, valves, compressors, or storage tanks, while liquid fuels may leak from pumps, tanks, or valves. Furthermore, the accumulation of combustible dust, especially in the gas turbine's combustion chamber, can cause an explosion in the presence of a spark or hightemperature. The researchers emphasized the importance of proper maintenance, inspection, and cleaning of the gas turbine components to prevent these hazardous events.

Another study by Kim and Song (2017) identified that a malfunctioning fuel system, such as a failure of the fuel control valve,can cause fuel to accumulate in the combustion chamber, leading to an explosion. In addition, a cracked or damaged combustionliner or transition piece can also cause an explosion due to the release of high-temperature gases. The researchers also highlighted the importance of regular inspection and maintenance of gas turbine components to prevent potential failures that can cause fires or explosions.

According to research by Zhang et al. (2018), overheating of gas turbine components, such as the combustion chamber, can also cause fires and explosions. This can occur due to a malfunctioning cooling system or inadequate cooling of the components,which can cause the metal to expand and rupture. Furthermore, the buildup of soot and other deposits in the combustion chamber can also lead to overheating, which can ignite the fuel and cause an explosion. The researchers recommended the implementation of effective cooling systems and regular cleaning of the combustion chamber to prevent these incidents.

3. Methodology

Complex systems can be greatly disrupted by the emergence of failures, leading to production delays. To prevent such failuresduring the design, manufacturing, and operation stages, experts employ risk management techniques such as Failure Mode andEffects Analysis (FMEA). By conducting an FMEA for fire and explosion in gas turbines, potential failure modes can be identified and addressed before they occur, reducing the risk of equipment damage, injury, or production downtime.

Table 1. FMEA for fire and explosion at gas turbines in power generation plants

Failure mode Sequence No.	Subsystem Component	Failure Mode	Failure Cause	Failure Effect	S	O	D	RPN	Counter Measure	Recommended Action
1	Compressor	Over-Heating	Dirty compressor rotor	Fire or Explosion incident	10	4	5	200	Install temperature sensor	Regular maintenance

2	Combustion chamber (Fuel nozzle)	Flameout	Partial cloggage or blockage of fuel nozzles	Fire incident	8	7	6	336	install flame detector	Regular maintenance
		Instability of flame pattern	Irregular fuel-to-air ratio	Fire or Explosion incident	6	4	6	144	Proper air-to-fuel ratio	Adjust fuel pressure
3	Combustion chamber (Flame tube)	Hot spots on flame tub	Fault in cooling of flame tube and inequality in flame distribution around it	Fire incident	6	2	8	96	Thermal barrier coatings	Increase cooling airflow
4	Combustion chamber (Casing)	Flame leakage	Loosing smoothness of mating areas	Fire incident	5	3	3	45	install flame arrestor	inspect and repair any damage or cracks in the casing
5	Turbine (Nozzle)	Over-temperature	Burnt nozzle vanes	Fire or Explosion incident	10	3	9	270	Install temperature sensor	Regular maintenance
6	Auxiliary sys. (Fuel system components)	Post-shutdown fire	Shutoff valve remains open	Fire incident	5	3	3	45	install automatic fuel shutoff valves	ensure proper grounding and bonding
		Flame-out	Fuel contamination	Fire incident	7	6	1	42	Install backup fuel systems	Ensure proper fuel supply and pressure

Following the assessment of system failure modes, it is feasible to prioritize them by assigning scores and arranging them in descending order. The resulting ranking positions the more critical failures at higher ranks, with a decline in criticality as the rates increase.

Table 1 presents the identified critical failures of the system, with Flame-out and Over-temperature receiving the highest-ranking scores. The analysis of each employed method revealed a consistent trend in the scoring numbers, indicating the equivalent risk importance for the recognized failure modes of the system.

In the FMEA method, enhancing the availability of various system components and improving the reliability of system performance requires special attention to be paid to the most critical failure modes during the maintenance scheduling process. The outcome of utilizing the Failure Mode and Effects Analysis (FMEA) method is the identification of a scheduled plan for executing the necessary maintenance policy for Gas Turbine Power Plants (GTPPS). Subsequent evaluations utilizing the FMEA approach will result in a reduction of the Risk Priority Number (RPN) due to iterative analysis of system failures.

4. Data Collection

There are numerous causes for fire and detonation incidents at power generation plants, including gas turbine power plants, equipment malfunction, human error, and natural disasters. Frequency and severity can vary depending on plant age and maintenance, the quality of safety protocols and emergency response plans, and the regulatory environment.

According to a report by the National Fire Protection Association (NFPA), there were an estimated 1,000 structural fires reported in U.S. electric power facilities between 2011 and 2015, 75 of which resulted in explosions. The report also stated that electrical distribution and lighting equipment was the primary cause of fires in electric power facilities.

However, it may be difficult to obtain specific statistics regarding fire and detonation incidents in gas turbine power plants in the GCC or globally, as such incidents are not always publicly reported or exhaustively tracked. In terms of human safety, environmental impact, and economic devastation, even a single fire or detonation can have significant repercussions. As a result, it is imperative that power generation facilities have in place stringent safety protocols and emergency response plans to prevent and mitigate such incidents.

5. Results and Discussion

There are several explosion incidents that have happened in gas power plants and resulted in several injuries and economic losses in the past. In 2010 a catastrophic explosion has taken place in North Carolina that killed 6 employees and more than 50 people were injured, when a cleaning process was initiated in the gas pipe using natural gas at high pressure it starts to ignite and it caused an explosion according to NBC Connecticut, 2020. Recently the number of gas turbine explosion incidentshas significantly decreased after the health and safety regulations. However multiple accidents have occurred. In 2019 a massive explosion happened in New Orleans in the US that destroyed a major electric power plant. It was caused by an operator error, and it resulted in injuring two employees with severe burns (David, 2021). Moreover, according to New Indian Xpress 2020, an explosion of a gas power plant in Karnataka was initiated by an undetected oil leakage that caused a fire and 15 workers have painful burn injuries. The last accident caused the fatality loss of one employee and two others were severely injured due to a leakage issue of one of the pumps that caused an enormous explosion in Mumbai 2022 (Mendonca 2022). Gas turbine power plants can pose various fire and explosion hazards, some of which are listed in the below table:

Table 2. Gas turbine power plant fire & explosion hazards

Hazard Category	Description
Fuel leaks or spills	Highly flammable fuels such as natural gas or diesel can present a significant fire hazard if they leak or spill. To mitigate this risk, gas turbine power plants should have robust leak detection and containment systems in place.
Overheating or combustion	Gas turbines generate a substantial amount of heat, increasing the risk of fires or explosions if not effectively managed. This hazard can be caused by improper maintenance, equipment failure, or human error.
Electrical faults	Faulty wiring or equipment can cause a spark, leading to a fire or explosion that poses a risk to both the plant and workers. Proper installation and maintenance of electrical systems are essential to mitigate thishazard.
Equipment failure	Gas turbine power plants have numerous moving parts and complex systems that can malfunction or fail, potentially leading to hazardous situations. Common examples of equipment failure include faulty valves, pumps, or sensors.
Human error	Mistakes in maintenance or operation, failure to follow safety procedures or improper handling of equipment can result in hazardous situations in gas turbine power plants. Proper training and strict adherence to safety protocols can help mitigate this risk.

This metric presents a method for evaluating the potential hazards and consequences of various hazard categories in gas turbine power plants. The severity and probability of each hazard are rated using a low, medium, or high scale, and a risk rating is determined based on these factors. However, it's important to keep in mind that this is just one possible approach to assessing hazards, and a comprehensive analysis should take into account all relevant factors and be customized to the specific plant and its operational context.

Table 3. Gas turbine power plant fire & explosion hazards severity & probability

Hazard Category	Potential Hazards	Potential Consequences	Likelihood	Severity	Risk Rating
Fuel Handling	Fuel leaks or spills	Fire, explosion	High	High	Critical
Combustion and Overheating	Overheating or combustion	Fire, explosion	Medium	High	High

Electrical Systems	Electrical faults	Fire, explosion	Medium	Medium	Medium
Equipment Failure	Equipment failure	Fire, explosion	Low	High	High
Human Factors	Human error	Fire, explosion	Medium	Medium	Medium

6. Recommendation

To reduce the risk of fire and detonation at power generation facilities, a systemic strategy and mitigation plan addressing the following areas should be developed.

1. Use Fault Tree Analysis (FTA) in criticality analysis. By combining FTA with FMEA, redundancy can be more appropriately and effectively assessed, while also facilitating the examination of human error in the analysis.
2. Conduct a thorough hazard identification and risk assessment to identify potential sources of fire and detonation hazards. This should include an evaluation of the design, equipment, and operational procedures of the power plant to determine the probability and severity of prospective incidents.
3. Implement fire prevention measures to reduce the risk of ignition sources, such as regular inspections and maintenance of apparatus, the use of flame-resistant materials, and the implementation of heated work procedures.
4. Explosion Prevention: To mitigate the potential effects of a fire or explosion, implement explosion prevention measures, such as the use of pressure relief devices and explosion suppression systems.
5. Emergency Response: Create and implement a plan for responding to prospective incidents. This should include evacuation procedures, apparatus shutdown, and coordination with local emergency services.
6. Training and Education: Provide personnel with consistent training and education on fire and detonation hazards, preventative measures, and emergency response procedures.
7. Management of Change: Implement formal management of the change process to ensure that any modifications to the design, equipment, or procedures of the power facility are exhaustively evaluated for potential safety risks.
8. Establish a system of continuous improvement to review and update the risk assessment, prevention measures, emergency response plan, and training and education programs on a regular basis.

By addressing these factors, a systemic strategy and mitigation plan can be devised to reduce the risk of fire and detonation at power generation facilities. It is crucial to note that the implementation of this plan should be a continuous process that is continuously evaluated and updated to ensure the safety of personnel and the adjacent community.

7. Conclusion

In conclusion, fires and explosions in gas turbines are significant safety hazards that can have serious consequences, including injury, property damage, and loss of life. The main causes of these incidents include fuel leaks, mechanical failures, electrical faults, and human error. While these incidents are rare, they can be catastrophic, underscoring the importance of identifying and addressing potential hazards to prevent these incidents from occurring. Through our literature review, we have identified several best practices for preventing fires and explosions in gas turbines. These include regular maintenance, appropriate safety systems, training and procedures, risk assessment, proper combustion, and environmental controls. By implementing these best practices, gas turbine operators can reduce the risk of incidents and ensure the safe and reliable operation of these critical pieces of equipment. This study utilized the Failure Mode and Effect Analysis (FMEA) method, which prioritizes failures based on their Risk Priority Number (RPN), to analyze Gas Turbine Power Plants (GTPPS), during the analysis of primary subsystems and auxiliary subsystems, a total of 44 distinct failure modes were identified. Out of the identified failure modes, three are classified as critical system failures that necessitate the development of a specialized maintenance plan. In summary, while fires and explosions in gas turbines are rare occurrences, they have significant safety implications. It is crucial for gas turbine operators to be aware of potential hazards and implement appropriate safety measures to prevent these incidents from occurring. By doing so, we can ensure the safe and reliable operation of gas turbines and protect workers, property, and the environment from the devastating consequences of fires and explosions. Overall, the findings of this research paper underscore the importance of gas turbine safety and highlight the need for ongoing efforts to mitigate the risk of fires and explosions in these critical pieces of equipment. By taking a comprehensive and proactive approach to safety, gas turbine operators can ensure the safe and reliable operation of their equipment, protect workers and the environment, and prevent devastating incidents from occurring.

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