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Original

Failure Mode and Effects Analysis and Risk Priority Number in a Combined Cycle Power Plant

Elnaz Rahimi[1], Fateme Nakhjavani[1], Sara Safari[1], Hanieh Nematollahi[1], Samira Mardaneh[1], Amin Babaei-Pouya[1*]

[1] Department of Occupational Health Engineering, School of Health, Ardabil University of Medical Sciences, Ardabil, Iran• *Corresponding Author: Amin Babaei-Pouya, Email: amiin.pouya@yahoo.com, Tel: +98-45-33513775

Abstract

Background: Work-related accidents are one of the most important factors in the loss of human lives. With technology and industrial progress, the consequences of accidents due to hazards become more severe and may even stop the work of power plants. This study aimed to identify and assess the risk of hazards in a combined cycle power plant. **Methods:** The descriptive cross-sectional study was conducted to assess the risk of a combined cycle power plant using the FMEA method. Having studied various documentation and records, holding different meetings, and brainstorming, the risk priority number was calculated and corrective suggestions have been presented. **Results:** Out of a total of 74 identified risks, 34 (45.94%) were at high risk, and 40 (54.05%) were of medium risk. 85% of the risks had the highest severity levels that could cause explosions and fires, injuries, and burns. **Conclusion:** It can be mentioned that the risks associated with industries such as power plants were high and preventive measures in such places are very important. Identifying hazards and risk assessments with a standard method such as FMEA was a useful way to prevent accidents and human and financial losses.

Keywords: Risk assessment; FMEA; Combined cycle power plant; Fire and Explosion

Introduction

Nowadays, one of the most important factors in the loss of human lives is work-related accidents which is a threat to the development of any country.[1, 2] According to the ILO, about 317 million accidents occur annually and about 6,300 people are exposed to work-related illnesses. The cost of accidents is about 4 percent of the world's gross domestic product.[3] The incidences of work-related accidents in developing countries are higher than in developed countries.[4] According to available statistics, work-related accidents are the third leading cause of death in the world, and in Iran, these accidents are the second leading cause of death after traffic accidents.[5, 6] Industries are considered to be high-risk environments for human health due to many accidents.[7, 8] The electricity industry is one of the most important industrial and economic infrastructures in any country and has three sectors of production, transmission, and distribution.[9, 10] The combined cycle power plant is a large, high-tech industry with great financial value.[11] The industry uses gas and steam turbine engines to generate electricity. The generator of gas turbine generates electricity. The steam turbine also uses heat

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from the gas turbine to generate the steam needed and produce additional electricity.[12,13] With the complexity of technology and industrial progress, the consequences of accidents due to hazards become more severe and may even stop the work of power plants. For this reason, risk identification and prioritization of risk mitigation programs are important activities in operation and maintenance of a combined cycle power plant.[14]

Because of the dangerous consequences of an accident, such as deaths and the loss of equipment, etc. identifying, assessing, and controlling the risks has become especially vital.[15] Risk assessment is a process including three-steps that includes identifying all hazards, calculating risks, and suggesting control actions. One of the risk assessment techniques is Failure Mode and Effects Analysis-FMEA.[16] This method can help the classification of risks ruled by the factors of Severity (S), probability of Occurrence (O), and the probability of Detection (D).[17] FMEA technique is a systematic tool based on teamwork that is used to identify, evaluate, prevent, eliminate, or control the causes and effects of potential errors in a system or process. This method determines how the component failure mode in a system leads to problems in system performance.[18] In a study, the use of FMEA in various industries in Japan was examined and concluded that FMEA is a successful method for risk assessment in industries such as automobiles, electronics, power plants, etc.[19] In another study by Dong, Y, Y. Gu and X. Dong (2008), using the FMEA method, an optimum strategy for maintenance equipment at the power plant was selected.[20] The results of risk assessment at power plants in studies by Jozi and Pouriyeh (2011) and Shirlali (2014)[15, 21] showed that explosions and fires were the most important consequences of risks in this industry.

Furthermore, the review of related texts reveals that a power plant system faces many dangers and threats due to its size and complexity, and if any accident happens, it is economically, socially, and humanly significant and irreparable. The concern of the managers of the combined cycle power plants is to improve safety performance to prevent accidents and financial and life damage.[11] Identifying potential risks is essential to prevent accidents and improve safety performance. This study aims to identify and assess the risk of hazards in a combined cycle power plant, using the FMEA method. Such studies are important because they can lead to an approach for controlling hazards and preventing accidents.

Methods

This research is a descriptive cross-sectional study conducted to assess the risk of a combined cycle power plant. The selected units for risk assessment included mechanical and electrical units, instrumentation, operation, administrative part, storeroom, services, and canteen. After an extensive review, the FMEA method was selected for risk assessment. Failure mode and effect analysis (FMEA) is considered a useful tool in assessing potential risks and estimating the level of risks to manage and reduce risks to an acceptable level.[22, 23] Hence, FMEA has proved beneficial for the industry because of its profound advantages.[24] Initially, the research group listed the existing risks through studying various texts, holding different meetings and brainstorming, and enacting the views of the experts of the power industry. Next, according to the FMEA method, the risks were scored. Three grades for severity (S), occurrence (O), and detection (D) were identified for each risk and presented in Table 1. The assessment of the severity of the risk was based on the knowledge and expertise of the group members. The severity was assessed in two areas of safety and health and environmental issues. Human exposure to pollutants was considered in the field of safety and health. Items were scored between 1 and 5, where 1 stands for the least and 5 for the highest risk factor

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such as death or complete disability and exposure to pollutants that are unbearable for humans. In the environmental area, the physical, chemical, and biological impacts of risk on the environment and the amount of energy consumed that ultimately disrupt human life were investigated. Similar to the previous category, scores were allocated between 1 and 5 so that the highest risk was scored 5 for the consumption of 80% higher than the expected use of energy resources and a threat to human life.

The occurrence was additionally a statistical concept and based on the experience and knowledge of the risk assessment team. In Table 1, the probability score was from 1 to 5. Score 5 was considered the worst case, which refers to the probability of daily occurrence or more, the duration of the exposure over 8 hours, and the probability of performing the activity once a day.The probability of detection is a kind of assessment of the system's ability to identify a cause or mechanism of occurrence of a hazard. In assessing the amount of detection, existing safety controls were considered.[25] In Table 1, the probability of detection was examined in two areas of safety and health, and the environment. The detection scores were once more between 1 and 5, which means that the score increases as it gets harder to identify risk. Score 5 was related to an undetectable risk. By multiplying these three values, the risk priority number (RPN) was obtained.

$$\text{RPN (Risk Priority Number)} = S \times O \times D \qquad (1)$$

As reported in Table 2, RPN grades were divided into three rankings:[26, 27]

27 < high risk, 9 < middle risk < 27, low risk<9.

Results

The research team identified a list of 74 of the existing risks in the combined cycle power plant through interviews with experts, using their knowledge and experience, and reviewing documentation and records. Some of the highest risks are presented in Table 3. Using Tables 1 and 2 and expert judgments, the three factors, namely severity (S), occurrence (O), detection (D), i.e., (S, O, D) were determined for each of the risks, and eventually, the RPN was calculated. According to the results of the analysis, out of a total of 74 identified risks, 34 (45.94%) were in high risk (risks that require immediate corrective action) and 40 (54.05%) were in medium risk (risks that need to be corrected as soon as possible based on the status of the process).

In Figure 1, the number of risks for each unit is presented in two columns. One column shows the number of high risks, and the other shows the middle risks. As displayed in Figure 1, the highest numbers of hazardous risks were in mechanical and operational units. Risks of exiting the gasket from the flange due to its decrepit condition, vibration, leakage of the connections and flanges of the lines, the valves in the process of changing fuel from gasoline to gas or mixture, the mechanical failure and contact deflection in the tap changer during a daily observation of power transformers, were among the highest dangers leading to explosions and fires, injuries and burns.

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Table1. Safety, Health, and Environmental Hazards Assessment Criteria

Score / parameter		1	2	3	4	5
Severity	Safety and health	Irritation and Insignificant discomfort for staff- No physical damage-The amount of pollutant is very small	An outpatient injury- Rest less than 48 hours- Diseases that are treated quickly -Disruptions to daily work Temporarily-The amount of pollutant is lower than the standard.	Severe injuries and one week rest- Diseases that have a recovery time of more than a week- The number of pollutants at the standard level-Disruption of work for one week.	Organ defects and disorders in doing work and living for more than a month- Diseases that lead to medical rest for more than a month- The amount of pollutant is slightly higher than the standard	Leading to death or complete disability-Disruptions in life and work to the extent that they cannot work continuously- The amount of pollutants is much higher than the standard and intolerable for individuals.
	Environmental	Negligible effects-Low energy consumption	Making physical changes in the environment-Normal energy consumption- It causes public discontent.	Make chemical and biological changes-Consumption is more than 20% higher than expected use of energy resources-It interferes with minor activities and annoy personnel	Impact on climate change and disturbing ecosystem balance-Consumption is more than 50% higher than the expected use of energy resources-It can disrupt some activities and complaints of personnel.	Threatening human life and other living creatures-Consumption is more than 80% higher than the expected use of energy resources-Disrupts all activities.
Likely occurrence of unusual and normal activities		The probability of occurring once every few years-Exposure time less than 2 hours during shift-Probability of doing activities once every few years	The probability of occurring annually once or less-Exposure time 2 to 4 hours during shift- Probability of doing activities once a year	The probability of occurring monthly-Exposure time 4 to 6 hours during shift-Probability of doing activities once a month	The probability of occurring per week-Exposure time 6 to 8 hours during shift-Probability of doing activities once a week	The Probability of occurrence daily and more-Exposure time exceeds 8 hours-Probability of doing activities once a day
Detection	Safety and health	All people are able to identify the danger	Identifiable with existing equipment (80%)	Identifiable by experts and specialized equipment (50%).	With equipment and testing out of the site can be detected (20%)	Until the occurrence is unidentifiable
	Environmental	All people are able to identify with the eye	Identifiable with the sense of smell and the existing equipment	Identifiable by experts and specialized equipment	With equipment and testing out of the site can be detected	Until the occurrence is unidentifiable, it can be detected after the occurrence with specific tests

Table 2. Risk Grade Determination

Risk rating	The priority of corrective action	RPN
High risk	Immediate corrective action is required	Above 27
Middle risk	Corrective action based on process status is needed as soon as possible	9-27
Low risk	Risks are monitored and controlled	Less than 8

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Table 3. Highest Risks Identified in the Combined Cycle Power Plant

Row	Work process	Section	RISK	Effects	RPN	Recommended controls
1	Changing fuel from Gasoline to gas or mix	Operation	Exit the gasket from the flange due to oldness, vibration, and ...	Injury due to gas accumulation, explosion, and formation of flame	45	Visit Device parts and other related equipment
2	People Crossing on the site	Safety according to working conditions	the collapse of the walls and ceiling of the units and buildings on the personnel at the time of emergencies and operations	Death and severe damage	40	Personnel Training on Emergency Action
3	Transportation	Services	Crash due to vehicle technical defects	Damage to people and equipment	36	Obtaining a technical inspection of vehicles
4	Cooking	Canteen	Infecting food as a result of the ingestion of animals and vermin, such as mice and cockroaches	Microbial and viral diseases	36	Prevent the entry and replication of animals in the Canteen
5	Cleaning	Services	Non-disinfection and regular washing of toilets in areas and buildings	Accumulation of microbes and viruses	36	Daily and regular cleaning of toilets
6	Daily views of Power Transformers	Operation	Mechanical failure and contact defect in tap changer	Damage due to fuel oil exploding and fire	36	Periodic visits and testing of the tap changer and the corresponding oil Do not change the tap during the presence of people in the transformer
7	Changing fuel from Gasoline to gas or mix	Operation	Leakage of connections and flanges of the lines and valves (Chambers)	Injury due to gas accumulation, explosion, and formation of flame	36	Visit Device parts and other related equipment
8	Handling	Services	Cramps, for example, on the waist	Lumbar disc and lumbar spine injury	32	Ergonomic training and continuous monitoring
9	Repair and maintenance of 20 million liters fuel tanks	Mechanic	Fire or explosion in fuel tanks during cutting, welding, or crushing operations	Damage to people and equipment	30	Use of fireproof blankets, Good ventilation and Prepare fire extinguishing facilities
10	Repair and maintenance of heaters	Mechanic	Falling people when opening and closing a unit heater mounted at a height	Damage to people and equipment	30	Creating a suitable place for work and Use of Safety Harness
11	Welding	Mechanic	Explosion due to welding or cutting operations on flammable and explosive materials pipes	Damage to people and equipment	30	Disposal of flammable materials and cleaning and washing the lines before the operation

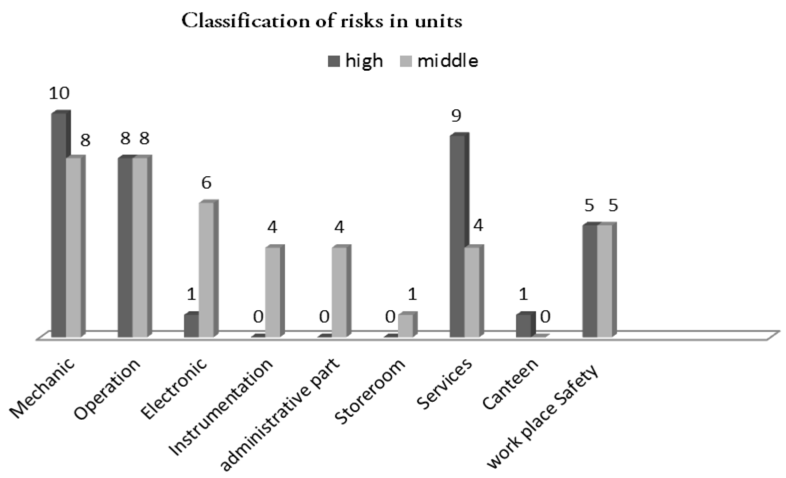

Figure 1. Classification of Risks in Units

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Dangers such as falling of people from the height during maintenance or scaffolding, load collisions with personnel when moving equipment and parts, possible explosions during welding and cutting, death and severe damages in crossing on the site at the time of emergencies were other issues of high risks which causes human and equipment damage. Overall, 85% of the risks had the highest severity levels, namely, the risk of death or complete disability in events such as explosions and fires, electric shocks, falling from the height during repair and maintenance operations of equipment, gas transmission lines, and valves. 56 (75.67%) of the risks had an annual rate of occurrence of one or less. The risk of lumbar injury due to carrying heavy load had the highest probability of occurrence per week. Moreover, the risks associated with the maintenance of the unit heaters, the displacement of equipment and parts, welding, and cutting could occur every month. 77% of the risks had the highest detection rates, which could be identified with existing tools. These risks included fire or explosion in fuel tanks during cutting, welding, or grinding operations, leakage of connections and flanges of lines and valves, removal of the gasket from the flange due to weariness, vibration, mechanical failure, and contact defect in tap changer. Some risks such as musculoskeletal, ocular, and neurological disorders in staff, microbial and viral contamination due to contaminated food or inappropriate cleaning, crash due to technical defects of vehicles or sleepy drivers, crane overturning, possible accidents when traveling on-site and hearing loss due to excessive sound exposure could be identified with special tools.

Discussion

The results of this study revealed that the most hazardous risks in a combined cycle power plant eventually lead to explosions and fires. This result was consistent with the studies of Shirali, Askaripoor, Kazemi, Zohoorian , Marzban (2014) and Askaripoor, Kazemi, Aghaei , Marzban (2015) at a combined cycle power plant using the degree of belief in fuzzy logic approach which "among the 11 cases of identified hazards, explosion and fire gas turbines and bust steam pipes under pressure ranked in the first place" (15, 28) and Jozi, and Pouriyeh's study (2011) on the risk assessment of the power plant using multi-criteria decision-making method.[21] In a further study on identifying risks at the Abadan gas plant, Jozi has shown that the risk of combustion in fuel tanks was relatively high.[29] In the studies of Aliabadi, Assari, Kalatpour, Zarei and Mohammadfam (2016) on oil and gas reservoirs, it has been claimed that the main cause of explosions and fires was the leak which is in line with the results of this study.[30]

The risk of injury to people in emergencies and fires was extremely high, and human errors and natural disasters were recognized as the main causes of their occurrence. To reduce human errors, measures such as safety training, using safety alarms, monitoring, and checking of work procedures must be carried out.[31] In the investigations of Jozi, Farbod, Arjmandi and Nouri (2013),[32] natural disasters were critical. Measures to prevent natural disasters included procedures, namely, modernization of equipment and strengthening buildings, preventive maintenance of equipment, training people, developing emergency response plans, and exercising periodic maneuvers.[33] Though 77% of the risk had a high detection rate in this study, failure of the protective systems, fuel leakage from the reservoirs, high heat, war, earthquake, sabotage and carelessness were among the most important causes of fire in the power plants, and if no measures are taken for such conditions, it will result in irreparable damages.[34] The existence of a firefighting network in power plants and evaluating its performance in emergencies is very critical. In this regard, in a study in 2018, a fire network hydraulic modeling has been developed in a combined cycle power plant to determine the efficiency of the fire extinguishing system.[35]

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Conclusion

The results of this study showed that 45.94 % of the risks were high, and 54.05 % of them were medium.

Therefore, it can be concluded that the risks associated with industries such as power plants are high, and the prevention of accidents in such places is very important. Establishment of occupational safety and health management system based on Iso 45000 standard and identifying hazards and risk assessment with an appropriate method such as FMEA, is a useful way to prevent accidents and human and financial losses. This risk assessment yields some key information, such as:

1. Determining the points that require optimization from the occupational safety and health perspective to reduce their risk to a tolerable level.

2. Prioritizing the most important risks and allocating financial, technical, and human resources to correct defects and improve conditions.

3. Determining the training content for employees in the field of occupational safety and health.

Finally, in consultation with experts and referring to standards, codes, and regulatory requirements, some corrective suggestions such as technical measures, training, instructions or procedures, and the use of personal protective equipment have been presented to eliminate or reduce identified risks. Corrective measures should be taken according to three approaches:

1. Reducing the likelihood of an error occurrence
2. Reducing the severity of the accident
3. Increasing the probability of error detection before the occurrence

FMEA is a formulated but subjective approach to risk identification and is typically implemented by a team of safety experts, design, and maintenance specialists.[36] The most important point is that using the FMEA method should not be simplistic, and risk assessment should be done carefully because the opinion of the team members is decisive. Accurate recognition of the system and, consequently, identifying system hazards, assigning exact numbers proportional to the actual likelihood of the occurrence or severity of the outcome of the risk, and finally, the decision on risk control are the three phases in the FMEA risk assessment. A mistake in each one distorts the evaluation results. Accordingly, some important risks in the allocation of resources and control measures may be ignored, increasing the potential for an accident. Some factors such as the cost which is effective in the severity rating have not been investigated in this research. The use of other improved methods that can investigate numerous hazard factors at the power plants would be effective in future studies.

Conflict of interest

The authors of this study state no conflict of interest.

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