Journal of Mechanical Engineering Research and Developments
ISSN: 1024-1752
CODEN: JERDFO
Vol. 43, No. 2, pp. 284-293
Published Year 2020

Qualitative Risk Assessment of Combined Cycle Power Plant Using Hazards Identification Technique

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ABSTRACT: This study is subjected to investigate risk during operation of combined cycle power plant using hazards identification technique. The study concentrates on anticipated risk governed with the normal operation of boiler, gas & steam turbines and generator systems, gas inventory system at typical combined cycle power plant. The assessment is conducted based on EVENT TREE analysis of the engineering safety feature systems contributed during the abnormal operation of the main systems. The identified hazards are classified according to their consequences and threats to the operation of the plant. Three main systems were chosen for the study in the combined cycle power plant which are the boiler, gas and steam turbines and generator in addition to gas inventory system. Risk and hazard are determined based on these three systems during the transient conditions. The hazards identification is analyzed through risk evaluation based on likelihood and severity of the hazards.

KEYWORDS: Qualitative; Risk assessment; Combined Cycle; Event Tree; Fault Tree; Hazardous Identification

INTRODUCTION

A combined cycle power plant is a plant that converts energy in natural gas / fuel into electrical energy involving the creation of mechanical loads, which are subsequently converted into electrical energy by a generator. "Combined cycle", is an expression referring to a multiple set of thermodynamics cycle to generate electricity. Combined-cycle power plants are a widespread method of generating electricity, along with other power plants such as hydroelectric power plants and coal power plants. Although power plants are safer than before, they are still a source of risk for workers. Therefore, it was necessary to develop a strategy that includes the identification and evaluation of major risks in order to achieve the necessary steps in determining and implementing risk identification elements during the operation of the plant and how to predict the probability of occurrence and severity [1].

The power plant is a requirement for generating power for the whole household and industry. Power plants vary in their types, which include: gas power plants, steam power plants, fossil fuel power plants, nuclear power plants and hydroelectric power plants. A power plant can be considered a workplace with a high level of risk, where safe working procedures are necessary, because workers face these risks and depending on the nature of tasks and jobs. According to the International Labor Organization (ILO) (2014), 2.3 million deaths are recorded annually. This means that every 15 seconds an accident occurs, in turn a worker dies doing work related to that accident or illness. In addition, 160 workers have accidents every 15 seconds. As a result 6300 people a day in work accidents or illness. Thus, this workplace is subject to potential accidents, due to the serious operating procedures of the power plant. Also, the OECD stated that more than 2,500 people are killed each year working in power plants related with severe accidents, [2].

Local electric power generation are made of various facilities and distributed according to their presence in the nearest place consumers can benefit from them, In addition to the power transmission facilities in the region. Studies related to the issue of risk management in the situation of developing the electric power production are usually specific. The main sources of industrial risk are categorized according to the phases of the work: during construction, during energy source planning and the procedures of development of the energy infrastructure platform. Several of studies revolve around issues related to logistical risk reduction, locating modern power and electricity plants in remote areas, environmental efficiency, accuracy and security of information, and investment rules related to complete repair and technical promotion of power plants, [3]. The most common accidents in the manufacturing processes of chemical industries are fire and explosion, which can lead to serious damage to properties and loss of major secondary hazards to those industries. Also, the emission of toxic substances is a common occurrence in these processes. Through cases of potential damage, this lead to serious injuries, loss of work and sometimes irreparable damage can also cause other costs such as premiums. This often leads to death and damage to property and assets, [4]. The importance of the safety of operations in power plants should exclude the severe consequences of such types of risks: fires or explosions that occur after the loss of fuel or in high-pressure steam equipment or catastrophic collapse of high-speed machines. These accidents have the potential to cause multiple injuries that may result in on-site and off-site deaths, as well as serious damage to assets and loss of long-term production.

The Process Risk Review (PRR) technology developed at beginning of 1990s is intended to accelerate hazard assessment for process safety within existing industrial plants. PRR has been widely used in factories in most manufacturing processes, especially in recent years for sites under Control of Major Accident Hazards (COMAH) regulations. It makes available a high-level assessment of the entire process, highlighting areas of concern and helping demonstrate continuous improvement in process safety. ABB has successfully used PRR in the power generation field and has made changes to comprise the assessment of HV power systems, [5]. The concept of Risk-Based Inspection (RBI) has also been applied to fossil power plant main components such as boiler elements, where the expert system uses RBI, called IRIS-THERMO. The first step starts from creating an app for a system with identified number of components. The data is then collected and validated. Three forms of assessment levels are applied (sorting or checking, intermediate and detailed). The risk matrix is then determined, which works in two directions: the direction of knowing the probability of failure and the other way of knowing the consequences of that failure. At the level of sorting and checking analysis, design, manufacture and operation dates shall be observed. In the intermediate analysis, the method of A-parameter metallographic technique is used. Through detailed analysis the expert system database is used where the fatigue and creep dates are used for steel evaluation. This modern approach, when implemented, allows for safe operation in the evaluation of system components. This is reflected in lowering the costs of inspections and maintenance, [6]. The risk assessment matrix could be applied to risk ranking procedures by type of risk and probability of occurrence. This assessment helps determine the risk assessment values based on severity and probability. This value in the classification of diverse risks, often used by the type of risk associated with it. It is therefore necessary to develop a system to determine the level of risk involved, which will help identify actions taken to eliminate or control risks. An inappropriate risk assessment tool will enable decision makers to understand the level of risk correctly, in determining time and cost, to reduce risk to a satisfactory level. Assess the impact, incidence and consequences of human activities on systems with hazard characteristics, based on the identification of risks as a fundamental and systematic process, [7]. A comprehensive review on the major blackouts and cascading events that have occurred in the last decade are introduced. A particular focus is given on the US power system outages and their causes since it is one of the leading power producers in the world and it is also due to the ready availability of data for the past events. The paper also highlights the root causes of different blackouts around the globe. Furthermore, blackout and cascading analysis methods and the consequences of blackouts are surveyed. Moreover, the challenges in the existing protective schemes and research gaps in the topic of power system blackout and cascading events are marked out. Research directions and issues to be considered in future power system blackout studies are also proposed, [8]. The aim of the recent research is focused on qualitative risk assessment for the combined cycle power plant using hazards identification technique for identifying the initiating events. The objectives are clarified by classifying the engineering safety features systems that are contributed during accidents scenarios. Two typical event trees of selected initiating events are identified as case studies for such power plants.

QUALITATIVE RISK ASSESSMENT

Qualitative risk assessment is a method used to estimate the risks related to specific hazards. Risk assessment is used for uncertain events that can have many consequences and which may have major consequences. Risk is a function of probability of an event (a particular hazard occurring) and the consequences given the event occurs. The probability of an event is a function of (a certain risk occurs) and the occurrence of the specific consequences of the event. Qualitative assessments are considered good in the evaluation of the showing levels when comparing/ examining multiple alternatives or when necessary to support the possibilities or results estimates resulting data are not available. [9].

Risk Assessment Tools

Hazard and Operability Procedure (HAZOP)

"HAZOP" is a way to identify threats. Its approach is based on guide words, which allow the development of various scenarios. This method is looking for determining the operative or safety issues associated to some divergence parameters or process variables. It takes into account the natural purpose of the operations or items of equipment and a comprehensive analysis of possible divergence scenarios.

Fault Tree Analysis (FTA)

A deductive approach to identifying all errors is the FTA that can lead to an unwanted event, termed the 'Top Event'. (FTA), represented by rational tree-shaped relationships called a "Fault Tree". The "Top Event" is the beginning, in which its causes or group of causes is determined, which can lead to its occurrence.

Event Tree Analysis (ETA)

The rational and independent technique that is used to determine the possible consequences of an undesirable event termed (ETA). "Event Tree" design starts from the unwanted event. Then all likely consequences for this event are identified. The consequences can be possible accidents.

Failure Mode, Effects and Criticality Analysis (FMECA)

The technique that goals to evaluate the frequency and loss of system failure and its consequences, to determine current preventive measures and to identify mitigation measures when risks are high are 'FMECA'. The methodology of FMECA is defined as:

1. Study system analyzing of all present information;
2. Identify the modes, reasons and outcomes of failure;
3. Determine the extent of the incident, the results of the severity and the possibility of protection failure;
4. Identify ranks of hazard tolerance;
5. Identify mitigation measures;
6. Measure the residual hazard.

The risk matrix is used in the hazard classification technique or by calculating Risk Probability Number, RPN as shown in the equation as follows:

$$RPN = F * P * C$$

Where,
F: Frequency of the failure type;
P: Probability of the existing protections fail;
C: The effect of the results that may ensue.

FMEA permits identifying areas involving problems and patterns of potential system failures and the need to take remedial action, which helps administration in decision-making. [10].

Methodology

Probabilistic risk assessment is based on quantifying the failure rates of engineering safety features systems beyond any initiating event. The quantification process depends on identification of hazard and assessment of risk. From other side, deterministic procedures highlighted products, equipment and quantification of the numerous objects for example individuals, situation and equipment during risk assessment. Quantitative approach of failure probability depends on the possibility or frequency of dangerous phenomena or when a potential accident occurs. Quantitative procedures are to analyze various data numerically. Steps to identify hazards and assess risk are:

Step1: System Description: Identify system, its subsystems and related processes.
Step2: Risk Identification - Identify and describe the risk, comprising its physical features, level and severity, the causative aspects and the positions or locations affected.
Step3: Risk study - Probability study, frequency or probability of possible injuries related to the risk.
Step4: Risk classification - A table of risk screening and classification is constructed for the calculation of: risk value, risk category and the Actions that can be taken.
Step5: Risk Resolution - recommended remedial action, prevention, reduction or transfer of risk through short and long term planning, [11].

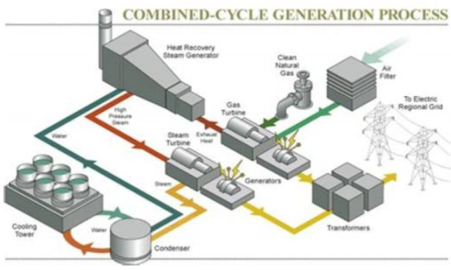

Figure 1. Combined cycle power plant

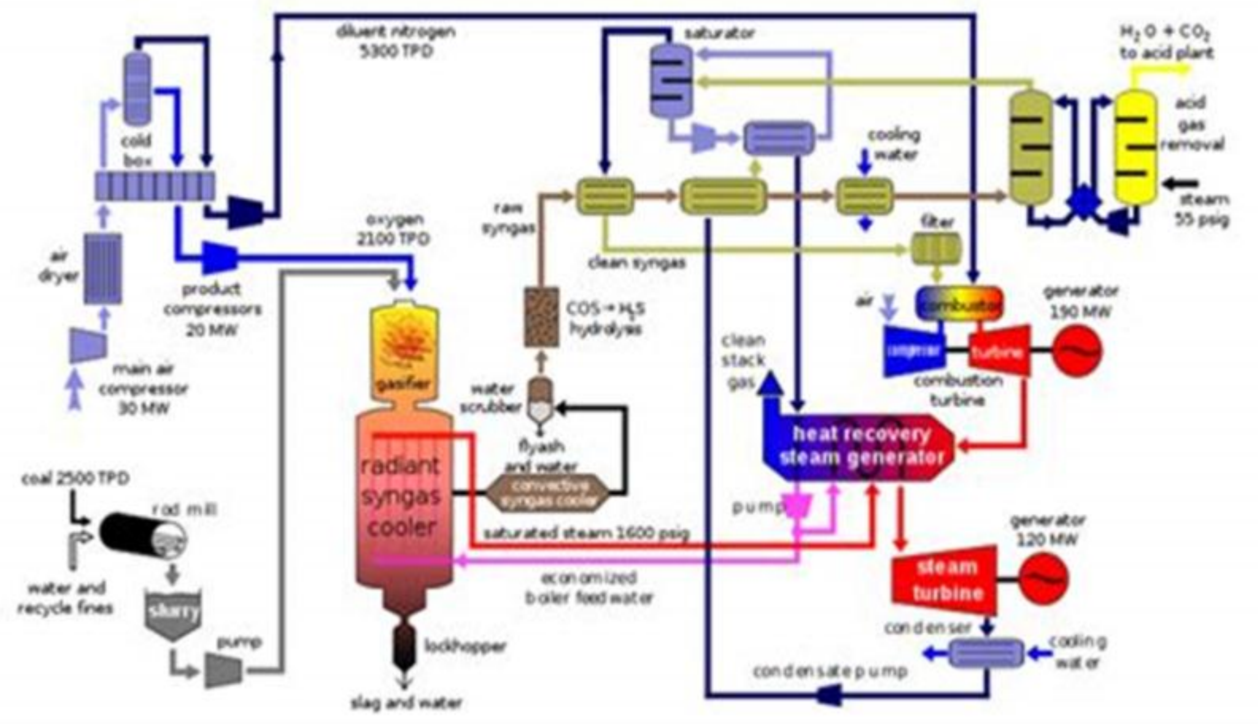

Figure 2. Process flow diagram in combined cycle power plant

HAZARD IDENTIFICATION FOR CASE STUDY

The case study takes under consideration the identification of hazards initiated from Gas inventory used for gas turbine operation, steam boiler, gas and steam turbine system and generator in combined cycle power plant as illustrated in Figures 1 and 2.

Fuel gas system

Occupies the higher risk source in the plant based on the principles of maximum leakage or explosion frequency and consequence. So, the project needs to improve awareness of the safety of all workers, and the impact of the abnormal detection system is the largest. The compressed gas storage accident simulates the disaster situation by completely ripping the tube, the large hole leakage and the accident in the middle hole. The result of the accident is that the radius of death depends on the gas supply and workers in the area, [12].

Steam boiler

Is used to convert water into high pressure steam by the burning of fuel in the closed chamber which is surrounded by steam and water tubes. The main failures of steam boilers include dry firing or overheating (44%), operator error (34%), explosion or overpressure, furnace explosion, corrosion and scale, and cracking. Boiler tube failures continue to be the leading cause of downtime for steam power plants. Risk associated with boiler operation included in Table 1.

Gas and steam turbines

Are rotary heat engines that convert energy of high pressure and high temperature steam into electrical energy by acting as the prime mover for generator rotation. The function of the generator is to convert the mechanical energy from the turbine to electrical energy [13]. Risk associated with turbine operation included in Table 1.

The generator

Translates mechanical energy from the turbine into electrical energy. Risks associated with generator operation are included in Table 1. Other fire and explosion risks could be initiated in lubricating oil system, cable gallery, fuel oil handling and power transformers, [14].

Figure 3 Shows the event tree diagram that represents the interaction of the events after flammable fuel spillage or leakage. The qualitative analysis is based on highlighting the expected outcomes from such initiating event. Events sequential propagation is defined and the expected outcomes for scenario are qualified. Another event tree diagram is shown in figure 4 that represents the interaction of events that follows the high pressure and temperature inside steam boiler beyond system design limitation.

CONCLUSION

Qualitative analysis of the anticipated risk in the dual cycle power plant is conducted based on identifying sample of the initiating events shown in table 1 that causes the major hazards which are mainly classified as local explosions and / or fires. Two typical initiating events are discussed and clarified. The first typical event tree shown in figure 3 illustrates the main events related to the expected interactions of the systems lead to the major hazards based on flammable fuel spillage initiating event. Engineering safety features systems here are identified by the fire alarm and sprinkler systems, while additional events are combined to event tree related external events related to the metrological factors. Enhancement of the analysis outcomes from safety viewpoint is dependent on the enhancement of the reliability of these two systems. Quantitative analysis of systems reliability is required during decision making. It is clear that the structure of the event tress is simple due to limited interactions of the engineering safety feature systems related to such initiating event. Another typical event tree is shown in Figure 4, illustrates the effect of the success and failure of some engineering safety feature components and systems on the expected sequential events following the fall of water level inside steam boiler. In this case study the contributed factor is classified to systems failures for example: Electrical power supply, water supply system, fuel supply control system, components failure for example: stem carrying pipes and safety valve, in addition to the effect of human reliability during accident course. The decision making on engineering safety features systems and components enhancement depends on optimizing between saturation level of such systems reliability and the additional cost required for such enhancement. In general the event trees related to the initiating events expected in conventional power plants are simpler than those related to nuclear power plants, justified by the limited major hazards that could be anticipated in such plants in comparison with nuclear power plants and the less complicity of the engineering safety feature systems in the earlier.

Table 1. List of the initiating events which leads to the major hazards in dual cycle power plants

No.	Component	Initiating events	Probable Hazards and/ or consequences
1	**Fuel supply system**	• Flammable fuel spillage due to pipe break or reservoir failure.	Fire and /or local explosion
2	**Steam boiler**	• Overheating results when the boiler operation continues after the water level has fallen below the minimum safe operating level set by the boiler manufacturer. • Fire hazard at the fuel firing area. • Risk of explosion in the mills when firing high Volatile Matter coal. • Risk of explosion due to abnormal pressure and temperatures • Overheating and exposure of coal to hot surfaces.	Fire and /or local explosion
3	**Gas and Steam Turbines**	• Loss of lubrication causing internal rubbing and the destruction or casing of the bearings. • Turbine over speed causing severe damage due to imbalance, higher vibration etc. • Water induction can cause any of the following: rub damage, thrust bearing destruction, blade damage, thermal cracking, warping distortion and possible casing damage. • Motoring due to generator circuit breaker failure to operate following a shutdown or trip. • Higher vibrations may lead to damage to journal bearing and other internal components. • Fire hazard at lube/hydraulic/seal oil system. • Poor water and steam quality can lead to internal corrosion and erosion leading to successive damages. • Foreign objects causing impact damage to blades and internal components.	Fire and/or damage of some internal parts

4	**Generators**	• Foreign objects damaging rotor and stator • Partial discharge can damage windings and result in a ground fault. • Overheating will cause insulation deterioration, resulting in ground fault, shorted turns. • Failure of retaining ring at high speed. • Vibration and mechanical looseness of stator components result in ground faults, phase-to-phase short circuit, or winding damage. • Localized overheating can cause vibration and winding ground faults. • Rotor winding fatigue causes cracking. • Core overheating will result in stator winding. • Stator core lamination short. • For hydrogen cooled generators, failure in oil retaining ring may lead to leakage of hydrogen. • Leakage in stator water cooling system may lead to ingress of hydrogen into water thus leakages leading to further damages.	Fire and/or damage of some internal parts

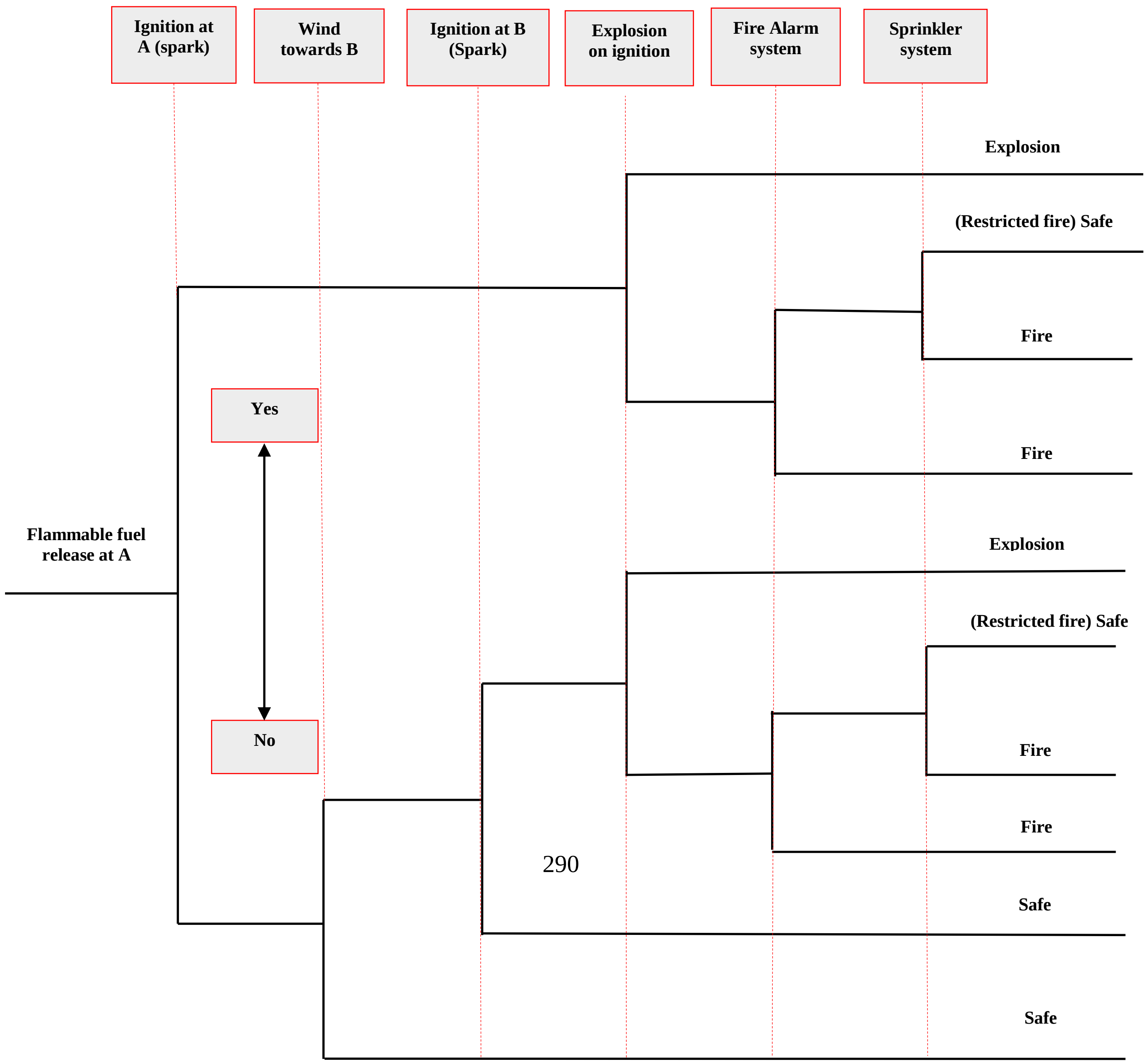

Figure 3. Typical event tree for flammable fuel spillage initiating event

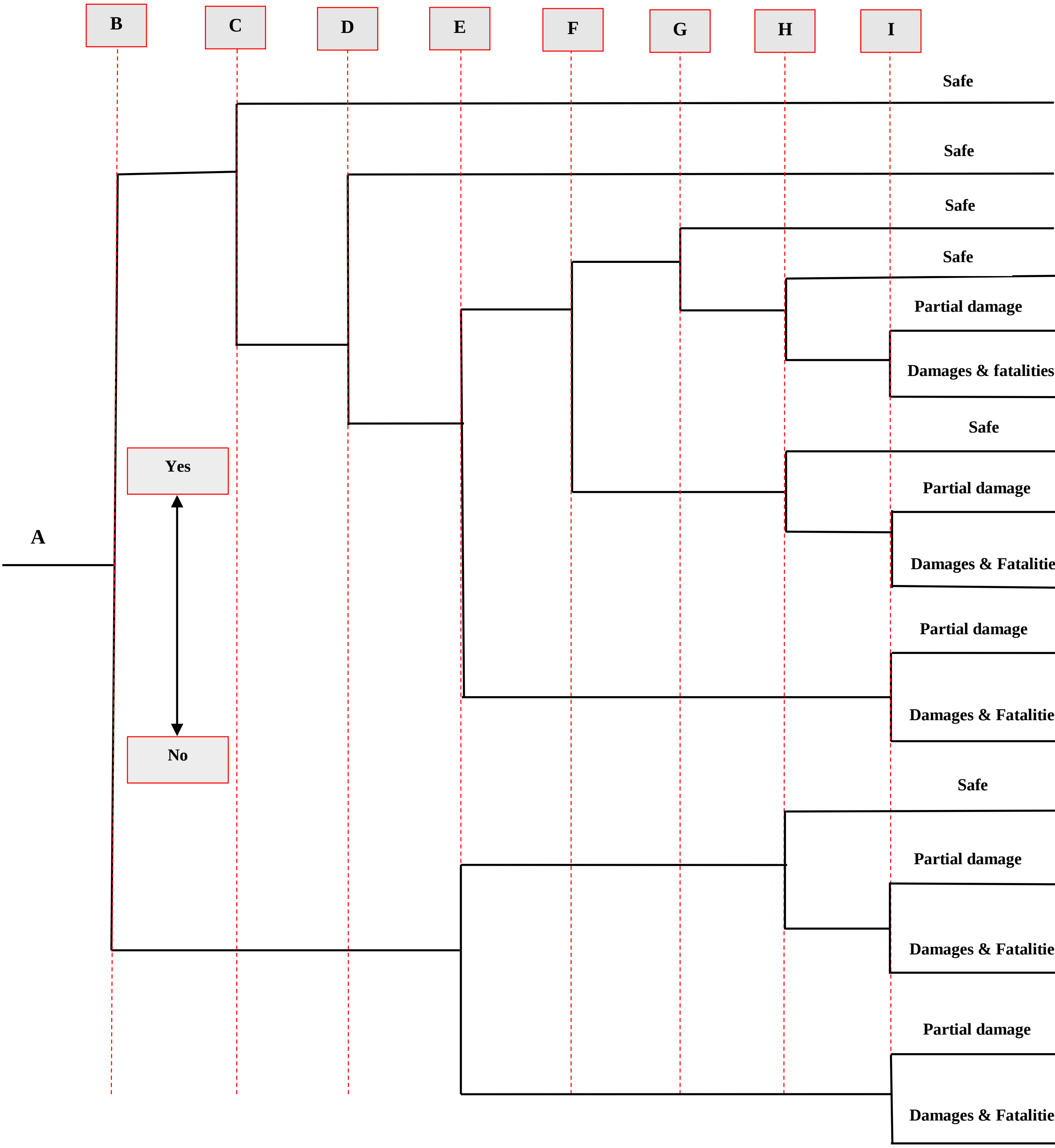

Figure 4. Typical event tree for an initiating event that represents water level fall below design limit inside steam boiler

Where:

A: Water level fall below design limit inside steam boiler.
B: Electrical power supply system succeeds to supply electricity.
C: Water supply system succeeds to compensate water level inside steam boiler.
D: Fuel supply control system succeeds to shutdown fuel supply to steam boiler.
E: Steam carrying pipes of the drum ensures its integrity up to trouble shoot pressure based on design of inspection procedure according to international codes and standards.
F: Success of over pressure and temperature alarm system.
G: Operator succeeds to shutdown steam boiler.
H: success of safety valve to relieve pressure.
I: Overpressure blast mitigation barriers success to protect operators and equipment beyond steam boiler

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