Quantitative and Qualitative Methods of Risk Assessment in Garry Thermal Power Plant

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Abstract - *Thermal power plant is considered to be a very risky industrial plant since it consists of a number of processes to generate electricity by use of fossil fuel. Hazard identification and risk assessment for Sudanese thermal power plant is conducted to identify physical, chemical, biological and environmental hazards in the plant. Also, to analyze the event sequences leading to those hazards and to calculate the frequency and consequences of hazardous events. Then the risk level is assigned to each hazard for identifying required corrective action to minimize the risk or eliminate the Hazard. Quantitative risk assessment and fire dynamics tools are used together with qualitative method to analyze the thermal power plant. Fire dynamic tools were developed by using state-of-the-art fire dynamics equations and correlations that were preprogrammed and locked into Microsoft Excel spreadsheets (gasoline, diesel and heavy fuel oil tests). It is found that gasoline as a fuel has higher heat release rate, lower burning duration, and higher radiative heat flux than diesel and heavy oil. Therefore, gasoline is more hazard than diesel and diesel is more hazard than heavy oil in all the unit stages.*

Key Words: Power plant, Garry, Risk assessment, hazardous events, Fire dynamic tools

1. INTRODUCTION

Risk is always associated with the frequency of failure and consequence effect. Predicting such situations and evaluating the risk is essential to take appropriate preventive measures. The major concern of the assessment is to identify the activities falling in a matrix of high and low frequencies at which the failures occur and the degree of its impact. The high frequency, low impact activities can be managed by regular maintenance whereas, the low frequency, high impact activities (accidents) are of major concern in terms of risk assessment. As the frequency is low, often the required precautions are not realized or maintained. However, the risk assessment identifies the areas of major concerns, which require additional preventive measures. The aim of hazard identification is to develop a comprehensive list of risk sources and events that might have an impact on the achievement of each of the objectives (or key elements) identified in the context. This step in the risk assessment process involves the identification of hazards and the determination of their causes. Hazard identification is the process of defining and describing a hazard, including its Physical characteristics, magnitude and severity, probability and frequency, causative factors, and locations or areas affected.

Thermal power plant is an electricity generation plant, which converts the fuel-stored energy to electrical energy by means of generating electricity. In other words, it is merely a chain of energy conversion as follow:

- Chemical energy in the fuel is converted to heat energy of steam
- Heat energy of steam is converted to mechanical or rotating energy of a rotating wheel called turbine.
- The mechanical energy of the turbine is converted as electrical energy in a generator.

1.1 Thermal Power Generation Plants in Sudan

In a revised feasibility study [1], the Sudanese thermal power generating (STPG) company is planning to construct a 600 MW coal fired power station composed from two generating units with a capacity of 300 MW for each unit , the plant is associated with desalination plant on the Red Sea Coast north of Port Sudan . In addition to the power and desalination plant, the Project will include a number of infrastructure elements including the construction of a coal handling jetty, construction of a 220 Kv transmission for the power interconnection with Port Sudan. The Red Sea Coal Fired Power Plant and Desalination Project is being developed in recognition of the fact that there is a shortage of both electricity and water to satisfy the needs of the population of the Red Sea State. Furthermore, the Project forms part of the whole country represented in the Ministry of Water Resources and Electricity. A wider aim is to increase security of electricity supply and to meet safely the targets of grid expansion to cover the overall country un-interconnected areas with the National Grid. Total power produced at Port Sudan power stations in the period 2011-2016 is calculated by GWH shown in figure (1).

STPG is responsible for the operation of all fossil fuel based power plants of Sudan power grids currently, as it is detailed in table (1) below.

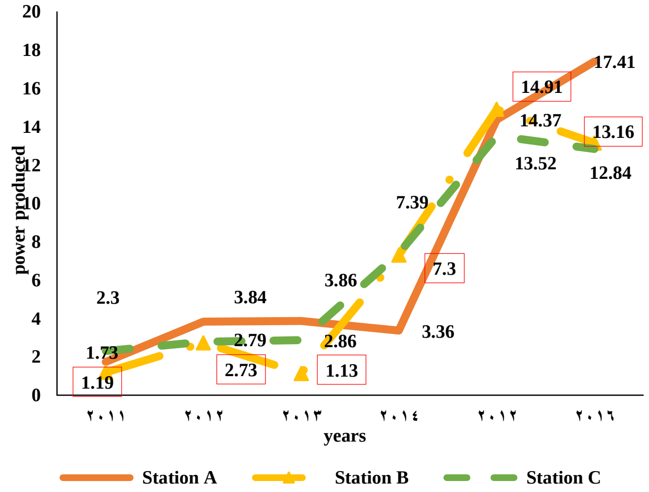

Figure – 1: Total power produced at Port Sudan power stations

Rabah, et al., [2], developed energy flow diagram (Sankey diagram) for Sudan in 2014. Their study provides important information on Sudan's energy sector covering supply and demand sides as well as conversion, distribution, and transmission. Sankey diagram is an important piece of information for decision-makers. It can be used to develop strategies and identify potential saving, opportunities, and mitigation measures. Ferreira [3] reviewed the concepts of methodology used for risk assessment of EDP power plant in Portugal. His analysis was carried out leading to the development of a risk treatment plan. Also Graeme R Ellis [4] described how a hazard identification and assessment methodology developed within the chemical sector and applied to operational Power Stations. He used process hazard review (PHR) which has been developed by ICI and became much quicker than HAZOP (hazard and operability studies); because it review each process system on a plant in sequence, such as a fuel storage system, and identifies credible hazardous events.

Table-1: Existing thermal power generation facilities [1]

Plant name and location	First year	Fuel oil type	Installed capacity
Khartoum north 1 + 2 Station	1984	HCGO	60 MW
Khartoum north 3 + 4 Station	1994	HFO & (HCGO)	120 MW
Khartoum north 5 + 6 Station	2011	HFO	200 MW
Khartoum north Gas Turbine 1 + 2	1992/ 2001	GO	50 MW
Garri-1 Block 1 + 2 CCGT*	2003	GO (LPG)	180 MW
Garri-2 Block 1 + 2 CCGT	2003/ 2007	GO (LPG)	180 MW
Garri 4 U 1 + 2 Station	2010	Sponge Coke	110 MW

*CCGT: combine cycle gas turbine

1.2 Problem Statement

The thermal power plant (TPP) consists several risk and hazard in their various part of plant and its operational processes. This may cause harm to people, property and environment. Those hazards are for example "Hazards in boiler room" which includes furnace, boiler tank, water and steam tubes and flue gases. The boiler room has risk of fire and explosion may cause due to improper ignition of fuel, lack of air supply in combustion chamber, over pressure and over temperature, cracks and metal fatigue in boiler body. Flue gas, the byproduct of combustion in the furnace, contains high pollutants like SOx, NOx, CO2 and fumes of heavy metals like arsenic (Ar), Mercury (Hg), Boron (B). When they emit in excess amount from the permissible limit can cause hazard to flora and fauna. There are several other hazards, which can be listed to be analyzed for reduction such like, electrocution, thermal exposure, physical hazard, chemical exposure hazard, noise in turbine room, chronic and acute health hazard.

Hazard analysis involves the identification and quantification of the various hazards (unsafe conditions) that exist in the proposed power plant operations. On the other hand, risk analysis deals with the recognition and computation of risks, the equipment in the plant and personnel are due to accidents resulting from the hazards present in the plant. Hence the main objectives of this work is:

1. Analyzing Data collected from plant and experiments.
2. Developing the assessment model process,
3. Identifying ways to control the hazards in thermal power plant generation unit (Decision making).

2. METHODOLOGY

An assessment of the conceptual design is conducted for the purpose of identifying and examining hazards related to feed stock materials, major process components, utilities and supported systems, environmental factors, proposed operations, facilities, and safe guards. The qualitative risk assessment method and Hazard analysis have been used, beside the quantitative risk assessment, which is done by fire dynamic tools.

2.1 Qualitative and Quantitative risk assessment

Hazard analysis include these five steps:

1. System description:
   There are four station in the Red Sea State, which are described as in table 2 below.

TABLE 2: Red Sea thermal power generation facilities

Station	No. of units	Capacity	Constructed on	Operation	Fuel
A	3	30 MW	2003	Seasonal (emergency)	–
B	3	5.7 MW	1983	Seasonal	Diesel/ gasoline
C	3	2.3 MW	–	2 units at work	Gasoline
D	2	150 mw	–	New	Gasoline /natural gas

Garri (El Jaili) CCGT Power Plant Sudan is located at Garri 80 km north of Khartoum, Sudan. This infrastructure is of type Gas Power Plant with a design capacity of 460 MW. It has two units. The first unit was commissioned in 2003 and the last in 2007. It is operated by National Electricity Corporation of Sudan (NEC). The combined cycle power plant (CCPP) consists of two 206B combined cycle, two gas turbine. Two HRSGs and one steam turbine are used in each block. Each gas turbine type is PG 6001B; its output is approximately 40MW for ISO condition, the gas turbine is normally operated with double fuel, LPG and light diesel oil. The gas turbine generator, which driven at 3000 rpm, is combined with air-cooler. Each gas turbine exhausts gases lead to its associated HRSG. There is a diverter damper between the gas turbine exhaust and the HRSG. It allows the gas turbine to operate either in open cycle mode or in combined cycle mode. The exhaust gas flow and temperature characteristics at the gas turbine exhaust will be changed with their load. The HRSGs are of the single-pressure type. The main steam lines of each HRSG are led to the steam turbine. The type considered is the extraction steam [5].

2. Hazard analysis:
   Hazard analysis involves the identification and quantification of the various hazards (unsafe conditions) that exist in the proposed power plant operations. On the other hand, risk analysis deals with the recognition and computation of risks, the equipment in the plant and personnel are exposure to, due to accidents resulting from the hazards present in the plant [6]. Risk analysis follows an extensive hazard analysis.

3. Risk assessment:
   Process safety is very important on power stations due to hazards such as fires or explosions following loss of fuel, explosions in high pressure steam equipment, catastrophic rupture of high speed machinery, or explosions in HV equipment. Such events have the potential to cause multiple major injuries or fatalities on-site or off-site, in addition to serious damage to equipment and extended loss of production.

4. Risk rating:
   Risk initiating event likelihood and consequences are assumed by taken reference of visited plant real activities. Risk Classification screening table is to be constructed.

5. Resolve the risk.
   Corrective action recommend preventing, reducing and/ transferring the risks, by short and long term planning.

2.2 Fire Dynamics Tools (FDT)

The U.S. Nuclear Regulatory Commission (NRC) has developed quantitative methods, known as “Fire Dynamics Tools” (FDTs) [7], for analyzing the impact of fire and fire protection systems in nuclear power plants (NPPs). These methods have been implemented in spreadsheets and taught at the NRC’s quarterly regional inspector workshops. The goal of the training is to assist inspectors in calculating the quantitative aspects of a postulated fire and its effects on safe NPP operation. The FDTs were developed using state-of-the-art fire dynamics equations and correlations that were preprogrammed and locked into Microsoft Excel spreadsheets for different types of fuel (gasoline, diesel and heavy fuel oil tests). These FDTs enable inspectors to perform quick, easy, first-order calculations for potential fire scenarios using today’s state-of-the-art principles of fire dynamics. Each FDTs spreadsheet also contains a list of the physical and thermal properties of the materials commonly encountered in power plants.

Four tests have been conducted for TPP when gasoline is used as fuel, while three tests have been conducted for TPP with diesel and heavy fuel oil. Test equations are as follows:

$$Q = \ddot{m}\,\Delta H_{c,eff}\left(1 - e^{-k\beta D}\right) A_{dike} \tag{1}$$

$$t_b = 4v/\pi D^2 n \tag{2}$$

$$H_f = 0.235\, Q^{2/5} - 1.02D \tag{3}$$

$$H_f = 42\, D\left(\dot{m}''/r_a \sqrt{(gD)}\right)^{0.61} \tag{4}$$

$$Q' = Q/L \tag{5}$$

$$\ddot{Q} = Qx_r/4pR^2 \tag{6}$$

$$q'' = E\, F_{-1>2} \tag{7}$$

$$\ddot{q}_r = 828(m_F)^{0.771}/R^2 \tag{8}$$

Tests results should be compared to get the optimum fire flame diameter, height and burning duration. In addition to the calculations of the radiative heat flux to a target fuel in presence of wind.

3. RESULT AND DISCUSSION

It is observed that risk assessment is very helpful for finding hazards conditions in power plant. Hazard analysis and risk assessment are used to establish priorities so that the most dangerous situations are addressed first and those least likely to occur and least likely to cause major problems can be considered later. For the risk rating step table 2 below is constructed to show the classification, screening of the risk and hazard description. Hazards were identified to analyze the risk at different sections of the thermal power plant sectors. The different activities were divided in to high, medium and low depending upon their consequences and likelihood. Frequency range of event has been established using a format that includes time between the occurrences, a qualitative description of these frequency range and categories or level of likelihood. A likelihood category chosen for the risk assessment to provide a frequency range to work when for example a likelihood category in table relates a frequency range and midpoint. In addition, the consequences relate the potential expected damage to property, people's life safety etc. The consequence rage is related to the qualitative losses data first on the base of life safety consequences and other property damage consequences. Figure 1 illustrates the likelihood levels and the consequence range.

Since, risk is defined as a measure of human injury, economic loss, and environmental damage in terms of both incident likelihood and magnitude of loss or injury, hence;

Risk = Probability of occurrence (likelihood) x Consequence of occurrence (severity)

Risk is commonly expressed as ranking/rating. This rating is typically simple to use and understand. It doesn't require extensive knowledge to be used and have consistent likelihood ranges that cover the full spectrum of potential scenarios. The risk matrix in Figure 1 below clarifies the above relationships.

Likelihood Table	
Level	Description
1	Rare
2	Unlikely
3	Possible
4	Likely
5	Almost certain

Consequence Table	
Level	Description
A	Catastrophic
B	Major
C	Moderate
D	Minor
E	Insignificant

		Consequence				
		Insignificant (E)	Minor (D)	Moderate (C)	Major (B)	Catastrophic (A)
Likelihood	Almost certain (5)	Medium	Medium	High	High	Extreme
	Likely (4)	Medium	Medium	Medium	High	Extreme
	Possible (3)	Low	Medium	Medium	High	High
	Unlikely (2)	Low	Low	Medium	Medium	High
	Rare (1)	Low	Low	Medium	Medium	Medium

Figure – 2: Risk matrix

Table 2: Risk Classification Screening Table

No.	Hazard Description	Initiating event likelihood	Unmitigated consequences		Risk Class
			Life safety	Risk Rating	
1	Turbine Hazard				
	Fire and explosion on hydrogen tank	5	5	25	A
	Explosion in turbine due to cooling system failure	5	5	25	A
	Fire on cooling oil	3	3	9	D
	High noise level	1	2	2	D
2	Boiler Hazard				
	Explosion in boiler due to over pressure and temperature	5	5	25	A
	Explosion in boiler due to improper combustion of fuel.	5	4	20	B
	Water tube burst due to Failure in boiler water level control	2	4	8	D
	Burn injury due to hot water and hot steam pipeline leakage	3	1	3	E
	Fire in diesel supply line	3	3	9	D
	Sleep , trip and from the height during routine work, maintenance or inspection	1	2	2	E
	Burn injury by hot fly ash	1	2	2	E
	Catches on the moving part of the machinery like F.D. fans or motors	2	1	2	E
	Burst of the equipment body due to over pressure and over temperature	3	1	3	E
	Exposure to the hot surface of pipeline or machineries	3	1	3	E
3	Switch Yard Hazard				
	Fire on transformer	3	1	3	E
	Electric shock and electric burn routine work, maintenance or inspection of electrical panels in switch yard	5	2	10	C
	Slip , trip and from the height during routine work, maintenance on switch yard	3	3	9	D
4	Other Hazard				
	Fuel discharge	5	2	10	D
	Fuel Handling	5	2	10	D
	Fire hazard on fuel storage tank	5	4	20	B
	Control room fire hazard	2	1	2	E
	Eye irritation and respiratory problem from the exposure of ammonia leakage from storage tank or pipeline	4	4	16	B
	Gas inhalation	3	1	3	E
	Hot surfaces injuries	4	1	4	E

The high risks activities have been rated '*A*' or '*B*' are un-acceptance and must be reduced. The risks which are rated '*C*' are tolerable but efforts must be made to reduce risk without expenditure that is grossly disproportionate to the benefit gained. The risks which are rated '*D*' or '*E*' have the risk level so low that it is not required for taking actions to reduce its magnitude any further.

The risk rating calculations were carried out by a qualitative method as mentioned in the table respectively. From table 2 for example there was hazards with high risk rating (*A* and *B*), so the corrective activities needed for preventing, reducing and/ or transferring the risks by short and long term planning as shown in table 3 below.

Table 3: Suitable Corrective activities for Risk Classes A and B

Hazard Description	Risk Class	Plan for corrective activities
Turbine Hazard		
Fire and explosion on hydrogen tank	A	• By using hydrogen sensors, for example, Multi IR flame detectors.
Explosion in turbine due to cooling system failure	A	• Back-up emergency feed water system. • Fire barrier for protection of control room. • Steam lines from the steam generator including safety and isolation valves.
Boiler Hazard		
Explosion in boiler due to over pressure and temperature	A	• The temperature sensors must be changed from time to time. • The oil viscosity must be kept in specific range. • The atomizing steam pressure and fuel oil pressure must be properly adjust.
Explosion in boiler due to improper combustion of fuel.	B	• Annual maintenance for the atomizer and air inflow (air blower). • Continuous inspection for the fuel properties to ensure that all the fuel has been burned instantaneously and there is no oil drops in the outflow flue gases. In addition to prevent incomplete combustion.
Other Hazard		
Fire hazard on fuel storage tank	B	• Annual maintenance and checking.
Eye irritation and respiratory problem from the exposure of ammonia leakage from storage tank or pipeline	B	• Annual maintenance and ensure using suitable personal protective equipment.

Liquid spilled onto the ground spreads out to form a pool. Volatile liquid (petroleum products) evaporate to atmosphere and soon form flammable mixture with air. Upon ignition, a fire will burn over the pool producing excessive amounts of heat. The heat vaporizes more fuel and air is drawn in round to the side to support combustion. Danger to people is by direct thermal radiation and burn. The pool fire result for random size spills using input parameters to the FDT tests for different fuels is estimated:

- For gasoline:

Area (ft^2)	Area (m^2)	Diameter (m)	Q (kW)	t_b (sec)	H_f (ft) (Heskestad)	H_f (ft) (Thomas)
1	0.09	0.34	114.85	2740.79	3.99	5.03
3	0.28	0.60	478.14	913.60	7.10	7.36
5	0.46	0.77	894.41	548.16	9.11	8.80
7	0.65	0.91	1331.80	391.54	10.66	9.89
9	0.84	1.03	1779.43	304.53	11.93	10.79
10	0.93	1.09	2005.44	274.08	12.50	11.19

- For diesel:

Area (ft^2)	Area (m^2)	Diameter (m)	Q (kW)	t_b (sec)	H_f (ft) (Heskestad)	H_f (ft) (Thomas)
1	0.09	0.34	95.47	4155.62	3.62	4.45
3	0.28	0.60	397.47	1385.21	6.45	6.52
5	0.46	0.77	743.51	831.12	8.28	7.78
7	0.65	0.91	1107.11	593.66	9.68	8.75
9	0.84	1.03	1479.22	461.74	10.84	9.55
10	0.93	1.09	1667.09	415.56	11.35	9.90

- For heavy oil:

Area (ft^2)	Area (m^2)	Diameter (m)	Q (kW)	t_b (sec)	H_f (ft) (Heskestad)	H_f (ft) (Thomas)
1	0.09	0.34	57.15	5645.59	2.74	3.82
3	0.28	0.60	246.60	1881.86	4.99	5.59
5	0.46	0.77	470.83	1129.12	6.47	6.68
7	0.65	0.91	711.24	806.51	7.62	7.50
9	0.84	1.03	960.72	627.29	8.57	8.19
10	0.93	1.09	1087.69	564.56	9.00	8.49

For pool fire area of 1 ft^2 (0.09 m^2) and pool fire diameter of 0.34 m;

$Q_{gasoline}$ = 114.85 kw, Q_{diesel} = 95.47 kw,
$Q_{fuel\ oil}$ = 57.15 kw

Gasoline has a higher heat release rate than diesel, fuel oil and crude oil, so it is the most dangerous among them. Same is found for the pool fire burning duration (t_b):

$t_{b\ \text{gasoline}}$ = 2740.79 sec, $t_{b\ \text{diesel}}$ = 4155.62 sec
$t_{b\ \text{fuel oil}}$ = 5645.59 sec

Gasoline has a low burning duration than diesel and heavy fuel oil so it is the most dangerous among them. For the Fire Flame Height:
$H_{f\ \text{gasoline}}$ = 3.64 m (*Heskestad*) and 3.29 m (*Thomas*)
$H_{f\ \text{diesel}}$ = 3.30 m (*Heskestad*) and 2.91 m (*Thomas*)
$H_{f\ \text{H. Fuel Oil}}$ = 2.74 m (*Heskestad*) and 3.82 m (*Thomas*)

It is observed that the flame height for gasoline is longer. Therefore, the gasoline is more risk than diesel and diesel is more risk than heavy fuel oil.

4. CONCLUSIONS

The data collected from Garry thermal power plant are analysis conclude the corrective activities needed for preventing, reducing and/ or transferring the risks by short and long term planning. Risk classes are determined from risk rating and life safety of every unit hazard description. The high risk activities have been rated *A* or *B* are unacceptable and must be reduced. On the other hand, from FDT tests, it is found that using lighter fuels (such as gasoline fuel) for power plant generation is more risky than diesel fuel and heavy fuel oil. From this analysis the Red Sea State thermal power plant generation units have to be upgraded to combined cycle power plant generation.

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