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Hazard And Operability Study for Determining Safety Integrity Level on Surface Above Ground System and Unit 1 And Unit 2 Geothermal Power Plant in Ulumbu Field

Gilang Romadhon[1,*] & Jooned Hendrarsakti[2]

[1]Faculty of Mining and Petroleum Engineering, Institut Teknologi Bandung, Jalan Ganesha 10, Bandung 40132, Indonesia
[2]Faculty of Mechanical and Aerospace Engineering, Institut Teknologi Bandung, Jalan Ganesha 10, Bandung 40132, Indonesia
*Email: gilangr3@gmail.com

Abstract. This study applies the Hazard and Operability (HAZOP) method to identify potential process risks and determine the Safety Integrity Level (SIL) of the Surface Above Ground System (SAGS) and Units 1 and 2 at the Ulumbu Geothermal Power Plant. Using process documentation, maintenance records, and operational data from 2020–2024, eight critical nodes were analyzed. Risk was evaluated using a matrix based on severity and likelihood, with failure probabilities derived from Mean Time to Failure (MTTF) and the OREDA database. The SIL assessment was conducted in accordance with IEC 61511. Results showed that most nodes operated under SIL 2, indicating a generally adequate safety system. However, several nodes—particularly those in the demister and lube oil systems—fell under SIL 1, suggesting the need for improvement. The study recommends additional shutdown valves to enhance protective functions, particularly in scenarios involving rupture disks. Overall, the findings provide insights into system vulnerabilities and support recommendations for improving the safety integrity of geothermal plant operations.

Keywords: *Hazard, Operability, Safety, Level, Risk, Assessment*

1 Introduction

Geothermal Power Plants (GPP) are recognized as a sustainable and environmentally friendly energy solution. With significantly lower carbon emissions than fossil fuels, geothermal energy plays a vital role in supporting the transition toward cleaner energy systems [1]. Report from Geological Agency in [2] Indonesia holds an estimated geothermal potential of approximately 24 GW, making it one of the countries with the largest geothermal resources globally. DiPippo in [3] explain that a key component of GPP infrastructure is the Surface Above Ground System (SAGS), which is responsible for transporting geothermal fluid from the wellpad to the separator. This system includes pipelines, separators, and wellpads, all of which must operate in coordination to maintain safety and efficiency. For the example, Andi et al in [4] the complexity of SAGS operations presents various hazards, such as fluid leaks, overpressure, and mechanical failures. Research has shown that continuum risk based method suitable for pipelines that are difficult to access with conventional thickness measurement method. One of the methods that will be used in this study is HAZOP. Definition from Kletz in [5] the Hazard and Operability Study (HAZOP) is a well-established method used to identify process deviations and associated risks, contributing to safer operations. In addition, this study using the Safety Integrity Level (SIL) from IEC 61511 to provides a quantifiable measure of risk reduction performance for safety instrumented systems, ensuring hazards are controlled within acceptable limits. This study aims to evaluate the SIL of critical SAGS components—including Units 1 and 2—based on HAZOP analysis. The goal is to provide actionable insights that enhance the overall safety and reliability of geothermal power plant operations at the Ulumbu Field.

2 Method of Studies

The data utilized in this study covers the process from steam gathering to Units 1 and 2 at the Ulumbu Geothermal Power Plant (PLTP). Nolan in [6], Yousefzadegan et al. in [7], Goharrokhi et al. in [8], Mohammedfam et al. in [9], Poulose and Madhu in [10], Musyafa and Kristianingsih in [11], Musyafa and Zulfiana in [12], Pandey Vaishnavi et al. in [13] this study using several documents such as Process Flow Diagram (PFD), Piping and Instrumentation Diagram (P&ID), Schematic Logic Control, Maintenance Data (Corrective Maintenance), and Operational Data. Maintenance and operational data were collected for the period 2020–2024 and were used to identify potential risks and failure probabilities. This study applies the Hazard and Operability (HAZOP) Analysis to identify risks throughout the entire operational process and employs the Safety Integrity Level (SIL) methodology to evaluate the effectiveness of the existing safety protection systems. Result from Noriyati et al. in [14], Jahanian and Mahboob in [15], Baybutt in [16], Abbasinejad et al. in [17], SIL give some recommendation of Safety Integrity System (SIS) to improve safety configuration in the location of study.

In the HAZOP methodology, risk is assessed through the use of a Risk Matrix, which evaluates hazards based on two key parameters: Likelihood and Severity. Likelihood represents the probability of a failure occurring in a specific component over a given time period. This probability is typically calculated using the Mean Time to Failure (MTTF), which indicates the average operational time before a component fails. The likelihood value is determined by comparing the total number of operating cycles with the MTTF, assuming continuous operation for 24 hours per day. This calculation allows for classification into defined likelihood categories. The explanation of likelihood is outlined in IEC 61511 and was adopted by Musyafa and Kristianingsih in [11], Musyafa and Zulfiana in

[12], Noriyati et al. in [14]. The likelihood is quantified using the following equation (1) and this study had five level which shown in table 1.

$$Likelihood = \frac{\text{period(hours)}}{MTTF} \tag{1}$$

Table 1 Likelihood

LIKELIHOOD ------>				
1	**2**	**3**	**4**	**5**
Failure occurs once in more than 10 years	Failure occurs once between 1 and 10 years	Failure occurs once a year	Failure occurs once a month	Failure occurs once a week
> 10 Years	1 - 10 Years	Annually	Monthly	Weekly

For components without available maintenance records, the MTTF is estimated using the failure rate (λ) data provided in the Offshore Reliability Data (OREDA) database, which has been validated through research conducted by Santorv et al. in [18] and Langseth et al. in [19]. OREDA has been used by Musyafa and Kristianingsih in [11], Musyafa and Zulfiana in [12], Noriyati et al. in [14], Wang et al. in [20], and Spruntrup et al. in [21]. In such cases, the MTTF is calculated using the standard reliability formula (Paul and Harry in [22]):

$$MTTF = \frac{1}{\lambda} \tag{2}$$

Table 2 Severity

SEVERITY	**CONSEQUENCE**			
	People (P)	**Environment (E)**	**Assets Loss (A)**	**Reputation (R)**
5	More than one fatality	Release of hazardous gas in significant quantity, requiring a long time to dissipate	Damage resulting in losses greater than IDR 10 billion	Attracts international public attention
4	Serious injury resulting in permanent disability	Release of hazardous gas in significant quantity, requiring a long time to dissipate	Major damage with losses less than IDR 10 billion	Gains attention at the national level
3	Serious injury requiring hospitalization, with potential for recovery	Hazardous release causing localized environmental damage	Damage resulting in losses less than IDR 1 billion	Attracts attention from local media and political stakeholders
2	Minor injuries requiring first aid or outpatient treatment	Hazardous gas release that dissipates in air or can be neutralized	Damage with losses less than IDR 100 million	Affects a portion of the community
1	No injuries or only minor scratches	Release of hazardous gas with no significant impact	Minor damage with losses less than IDR 10 million	No public disturbance

Severity, on the other hand, reflects the extent of impact resulting from a failure or hazardous event. It encompasses potential damage to equipment, human injury or fatality, environmental harm, and associated financial losses—including production downtime and recovery costs. Severity levels are classified based on the magnitude of these consequences which shown in table 2. Once Likelihood and Severity have been identified, the corresponding risk level can be determined based on Table 3.

Table 3 Risk Matrix

		LIKELIHOOD -------->				
		1	2	3	4	5
SEVERITY -->	5	M (5)	H (10)	H (15)	E (20)	E (25)
	4	L (4)	M (8)	H (12)	H (16)	E (20)
	3	L (3)	M (6)	M (9)	H (12)	H (15)
	2	L (2)	L (4)	M (6)	M (8)	H (10)
	1	L (1)	L (2)	L (3)	L (4)	M (5)

In IEC 61511 Safety Integrity Level (SIL) is a measure used to indicate the average failure tolerance of a Safety Instrumented Function (SIF), thereby setting the target risk reduction required for a given process. Simply put, SIL represents the performance level necessary for a specific SIF. There are four defined SIL levels, where SIL 4 represents the highest level of protection, requiring highly reliable safety instrumentation, and SIL 1 represents the lowest acceptable level of performance. The determination of SIL level is based on several factors, including lifecycle process development and safety management. Each functional safety standard specifies different requirements for SIL classification. According to the study conducted by Jahanian and Mahboob in [15], Echeverria in [23], Wu et al. in [24] and Khalil et al. in [25], once the SIL value has been determined, it serves as a basis for management to enhance process safety within an industrial setting. SIL levels are typically derived from the Probability of Failure on Demand (PFD) for each SIF, as shown in the table below.

Table 4 PFD (Probability Failure on Demand)

DEMAND MODE OF OPERATION		
Safety Integrity Level (SIL)	**PFD_{avg}**	**Required risk reduction**
4	$\geq 10^{-5}$ to $< 10^{-4}$	> 10000 to ≤ 100000
3	$\geq 10^{-4}$ to $< 10^{-3}$	> 1000 to ≤ 10000
2	$\geq 10^{-3}$ to $< 10^{-2}$	> 100 to ≤ 1000
1	$\geq 10^{-2}$ to $< 10^{-1}$	> 10 to ≤ 100

3 Risk Analysis

This study is limited to a specific system scope, focusing exclusively on Unit 1 and Unit 2, also referred to as the ADB Units of the Ulumbu Geothermal Power

Plant (PLTP). The system is divided into eight nodes, each representing a critical process area. These nodes are considered essential, as any disruption within them has the potential to halt operations of the respective unit.

3.1 Node 1 Steam Gathering

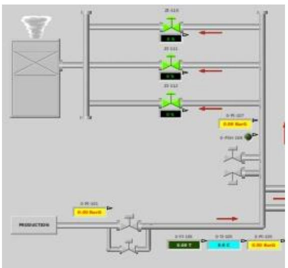

Figure 1. HMI Steam Gathering

Figure 1 is a Human Machine Interface of Steam Gathering System. It serves the dual function of measuring the steam flow rate directed to the ADB units and providing safety protection in the event of an overpressure condition.

This study focuses specifically on the process safety protection system within this node. Accordingly, the guide words, deviations, and likelihood estimations are presented in Table 5.

Table 5 Guide Word, Deviation and Estimation Likelihood Node 1

No.	Guide Word	Deviation	Tagging	Description	MTTF	Likelihood	Total	Score
			0 ZZ 110	ESD (Ball Valve)	280898.876	0.311856		
			0 ZZ 111	ESD (Ball Valve)	280898.876	0.311856		
1.1.7	More of	More of Pressure	0 ZZ 112	ESD (Ball Valve)	280898.876	0.311856	1.879896	2
			0 PAHH 107	Pressure Transmitter	188679.245	0.46428		
			0 PAHH 108	Pressure Switch	182481.752	0.480048		

Based on Table 5 above, the risk assessment results are presented in Table 6 HAZOP Worksheet for Node 1 below. The risk score for this node is 6 (Medium), indicating that a failure in this area could result in significant consequences and potential losses.

Table 6 HAZOP Worksheet Node 1 Steam Gathering

1. Parameter Pressure										
No.	**Guide Word**	**Deviation**	**Cause**	**Consequences**	**Index (S)**	**Safeguard**	**Index (L)**	**Risk Score**		
								S	**L**	**Risk**
1.1.7	More of	More of Pressure	Failure-Open in 0 PCV-110, 0 PCV-111 and 0 PCV-112	Stop operation GPP ADB (Unit 1 and Unit 2)	Medium	0 PAHH 107 0 PAHH 108 Emergency Shutdown RUPTURE DISK1 RUPTURE DISK2	Low	3	2	6

3.2 Node 2 and 3 Demister

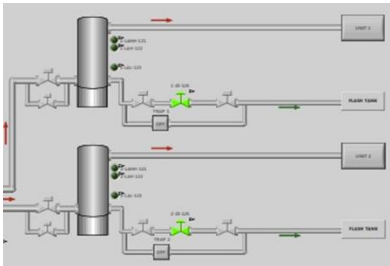

Figure 2. HMI Demister

Figure 2 is a Human Machine Interface of demister. It can reduce water particles and solid contaminants carried within the steam flow. Nodes 2 and 3 are identical in configuration; therefore, the guide words, deviations, and likelihood estimations are presented in Table 7.

Table 7 Guide Word, Deviation and Estimation Likelihood Node 2 dan 3

No.	**Guide Word**	**Deviation**	**Tagging**	**Description**	**MTTF**	**Likelihood**	**Total**	**Score**
2.1.1	More of	More of Level	1 ZZ-125	ESD (Gate Valve)	144717.8	0.605316	2.516748	2
			1-SD	Scrubber	280898.876	0.311856		
					280898.876	0.311856		
			1 LAHH 121	Level Switch	2173913.04	0.040296		
					70224.7191	1.247424		

Based on Table 7 above, the risk assessment results are presented in Table 8 HAZOP Worksheet for Node 2 and 3 below. The higher risk score for this node is 6 (Medium). If valve ZZ-125 failure open, water going to turbine and it have possibility to broke the turbine.

Table 8 Corrective Maintenance Node 2 and 3

1. Parameter Level										
No.	**Guide Word**	**Deviation**	**Cause**	**Consequences**	**Index (S)**	**Safeguard**	**Index (L)**	**Risk Score**		
								S	**L**	**Risk**
2.1.1	More of	More of Level	Failure- Open di 1 ZZ-125	Water Contain going to Turbine and causing Trip in Unit 1 / 2	Medium	1 LAHH 121	Low	3	2	6

3.3 Node 4 and 5 Turbine and Generator Set

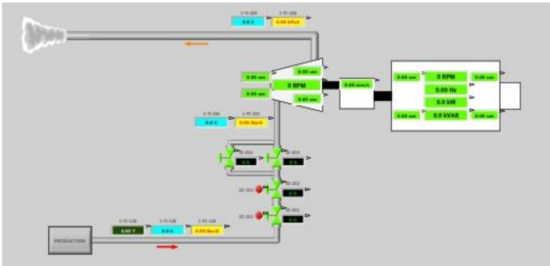

Figure 3. HMI Turbine and Generator

Figure 3 is a Human Machine Interface of Turbine and Generator Set. It is a core component responsible for converting steam energy into electrical power. This system includes several process variables that serve as safety parameters, such as pressure, temperature, level, vibration, and speed. Nodes 4 and 5 are identical in configuration; therefore, the guide words, deviations, and likelihood estimations are presented in Table 9.

Table 9 Guide Word, Deviation and Estimation Likelihood Node 4 and 5

No.	Guide Word	Deviation	Tagging	Description	MTTF	Likelihood	Total	Score
4B.1.1	More of	More of Temperature	1 TAHH 523/524/525/526	Temperature Transmitter	17099.8632	5.122848	5.517048	2
			1 ZZ 201	ESD (Butterfly Valve)	444444.444	0.1971		
			1 ZZ 202	ESD (Butterfly Valve)	444444.444	0.1971		
4B.2.1	More of	More of Speed	1 SSHH 531/532/533	Speed Switch	231481.481	0.378432	1.151064	2
			1 SAHH 531/532/533	Speed Transmitter	231481.481	0.378432		
			1 ZZ 201	ESD (Butterfly Valve)	444444.444	0.1971		
			1 ZZ 202	ESD (Butterfly Valve)	444444.444	0.1971		
4B.3.1	More of	More of Vibration	1 VAHH 505/505/507/508	Vibration Transmitter	59241.7062	1.478688	6.995736	2
			1 ZZ 201	ESD (Butterfly Valve)	444444.444	0.1971		
			1 ZZ 202	ESD (Butterfly Valve)	444444.444	0.1971		
4C.1.1	More of	More of Temperature	1 TAHH 517/518/519/520	Temperature Transmitter	17099.8632	5.122848	5.517048	2
			1 ZZ 201	ESD (Butterfly Valve)	444444.444	0.1971		
			1 ZZ 202	ESD (Butterfly Valve)	444444.444	0.1971		
4C.2.1	More of	More of Vibration	1 VAHH 509	Vibration Trensmitter	236966.825	0.369672	5.88672	2
			1 ZZ 201	ESD (Butterfly Valve)	444444.444	0.1971		
			1 ZZ 202	ESD (Butterfly Valve)	444444.444	0.1971		

4D.1.1	More of	More of Temperature	1 TAHH 511/512/513/514/515/516	Temperature Transmitter	17099.8632	5.12285	5.517048	2
			1 ZZ 201	ESD (Butterfly Valve)	444444.444	0.1971		
			1 ZZ 202	ESD (Butterfly Valve)	444444.444	0.1971		
4D.1.2	More of	More of Temperature	1 TAHH 521/522	Temperature Transmitter	34199.7264	2.56142	2.955624	2
			1 ZZ 201	ESD (Butterfly Valve)	444444.444	0.1971		
			1 ZZ 202	ESD (Butterfly Valve)	444444.444	0.1971		
4D.2.1	More of	More of Vibration	1 VAHH 501/502/503/504	Vibration Trensmitter	59241.7062	1.478688	1.872888	2
			1 ZZ 201	ESD (Butterfly Valve)	444444.444	0.1971		
			1 ZZ 202	ESD (Butterfly Valve)	444444.444	0.1971		

Based on Table 9 above, the risk assessment results are presented in Table 10 HAZOP Worksheet for Node 4 and 5 below. In this node have 4 Sub Node such as Inlet Turbine, Turbine, Gear Box, and Generator. The higher risk score for this node is 6 (Medium). In most cases within this node, abnormal parameters are primarily caused by overpressure at the unit inlet, which can automatically trigger a trip in the ADB unit.

Table 10 Corrective Maintenance Node 4

No.	Guide Word	Deviation	Cause	Consequences	Index (S)	Safeguard	Index (L)	Risk Score		
								S	L	Risk
B. Sub Node Turbine										
1. Parameter Temperature										
4B.1.1	More of	More of Temperature	Overheat on Thrust Bearing	Trip Unit ADB	Medium	1 TAHH 523/524/525/526 Trip Device 1 ZZ 201 1 ZZ 202	Low	3	2	6
2. Parameter Speed										
4B.2.1	More of	More of Speed	Over Pressure Steam into Inlet Turbine	Rotation of Turbine too fast and make over frequency Trip Unit ADB	Medium	1 SSHH 531/532/533 1 SSHH 531/532/533 Trip Device 1 ZZ 201 1 ZZ 202	Low	3	2	6
3. Parameter Vibration										
4B.3.1	More of	More of Vibration	Overspeed on Thrust Bearing	Loose Axial Turbine Trip Unit ADB	Medium	1 VAHH 505/505/507/508 Trip Device 1 ZZ 201 1 ZZ 202	Low	3	2	6
C. Sub Node Gearbox										
1. Parameter Temperature										
4C.1.1	More of	More of Temperature	Overheat on Thrust Bearing	Trip Unit ADB	Medium	1 TAHH 517/518/519/520 Trip Device 1 ZZ 201 1 ZZ 202	Low	3	2	6
2. Parameter Vibration										
4C.2.1	More of	More of Vibration	Overspeed Thrust Bearing	Loose Axial Gearbox	Medium	1 VAHH 509 Trip Device 1 ZZ 201 1 ZZ 202	Low	3	2	6
D. Sub Node Generator										
1. Parameter Temperature										
4D.1.1	More of	More of Temperature	Overheat on Stator	Trip Unit ADB	Medium	1 TAHH 511/512/513/514/515/516	Low	3	2	6

						Trip Device 1 ZZ 201 1 ZZ 202				
4D.1.2	More of	More of Temperature	Overheat on Thrust Bearing	Trip Unit ADB	Medium	1 TAHH 521/522 Trip Device 1 ZZ 201 1 ZZ 202	Low	3	2	6
	2.	Parameter Vibration								
4D.2.1	More of	More of Vibration	Overspeed on Thrust Bearing	Loose Axial Gearbox	Medium	1 VAHH 501/502/503/504 Trip Device 1 ZZ 201 1 ZZ 202	Low	3	2	6

3.4 Node 6 and 7 Lube Oil System Steam Gathering

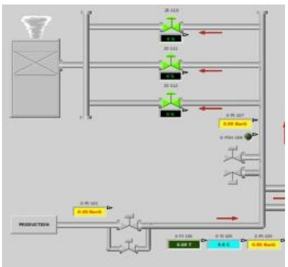

Figure 4. HMI Lube Oil System

Figure 4 is a Human Machine Interface of Lube Oil System. It is a set of equipment designed to circulate and purify the lube oil within the power generation system. Nodes 6 and 7 are identical in configuration; therefore, the guide words, deviations, and likelihood estimations are presented in Table 11.

Table 11 Guide Word, Deviation and Estimation Likelihood Node 6 and 7

No.	Guide Word	Deviation	Tagging	Description	MTTF	Likelihood	Total	Score
6.1.1	Less of	Less of Pressure	1 PALL 318/319	Pressure Transmitter	188679.245	0.46428	30.8387	3
			1 ZZ 201	ESD (Butterfly Valve)	444444.444	0.1971		
			1 ZZ 202	ESD (Butterfly Valve)	444444.444	0.1971		
			1-PU-2	Rotary Pump	5843.85227	14.990112		
			1-PU-3	Rotary Pump	5843.85227	14.990112		
6.2.1	Less of	Less of Level	1 LALL 307/308	Level Transmitter	250626.566	0.349524	0.7437	1
			1 ZZ 201	ESD (Butterfly Valve)	444444.444	0.1971		
			1 ZZ 202	ESD (Butterfly Valve)	444444.444	0.1971		

Based on Table 11 above, the risk assessment results are presented in Table 12 HAZOP Worksheet for Node 6 and 7 below. The higher risk score for this node is 6 (Medium). In this node, the main point of concern is the lube oil filter unit. As in most power plants, this component requires close attention, as any failure can indirectly impact the turbine and generator. Moreover, damage to the lube oil filter may result in prolonged downtime, making its reliability critical to overall system performance.

Table 12 Corrective Maintenance Node 6 and 7

No.	Guide Word	Deviation	Cause	Consequences	Index (S)	Safeguard	Index (L)	Risk Score		
								S	L	Risk
	1. Parameter Pressure									
6.1.1	Less of	Less of Pressure	No lube oil flow after the filter. Clogged lube oil filter	Overheating of the turbine and generator Bearing deformation in the turbine and generator	Medium	1 PALL 318/319 Trip Device 1 ZZ 201 1 ZZ 202 1-PU-2 1-PU-3	Low	2	3	6

3.5 Node 8 Aux Cooling System

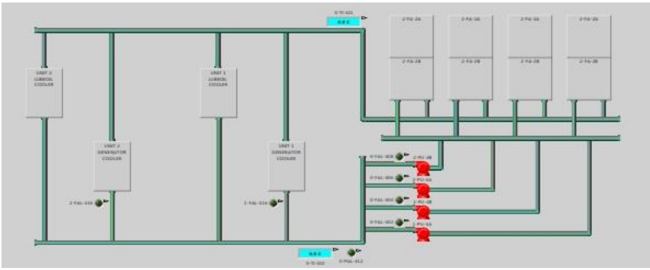

Figure 5. HMI Steam Gathering

Figure 5 is a Human Machine Interface of Aux Cooling System. It is a set of equipment designed to cooling all system in Power Plant. This node has a low risk score, indicating that no immediate improvements are required at this time.

4 Discussion

Based on the risk analysis conducted, 7 out of the 8 nodes were classified as having a Medium Risk level. Following this, preventive operational recommendations for the ADB unit were formulated, as presented in table 13 below.

Table 13 HAZOP Worksheet Node 1 Steam Gathering

No.	Recommendation	By
	NODE 1 STEAM GATHERING	
	1. Parameter Pressure	
1.1.7	Shutdown Unit 1 dan Unit 2 Operator closes Valve 0SB15-300C-T, which leads to ADB Units (#1 and #2)	Operation
	NODE 2 & 3 DEMISTER	
	1. Parameter Level	
2.1.1	When LAHH is triggered, the operator opens Gate Valve SB09-40E	Operation
	NODE 4 & 5 TURBINE AND GENERATOR SET	
	B. Sub Node Turbine	
	1. Parameter Temperature	
4B.1.1	Operator adjusts the opening of ZC 201/202 once PAH 205 is activated	Operation
	2. Parameter Speed	
4B.2.1	Operator adjusts the opening of ZC 201/202 once PAH 205 is activated	Operation

	3. Parameter Vibration	
4B.3.1	Operator adjusts the opening of ZC 201/202 once PAH 205 is activated	Operation
	C. Sub Node Gearbox	
	1. Parameter Temperature	
4C.1.1	Operator adjusts the opening of ZC 201/202 once PAH 205 is activated	Operation
	2. Parameter Vibration	
4C.2.1	Operator adjusts the opening of ZC 201/202 once PAH 205 is activated	Operation
	D. Sub Node Generator	
	1. Parameter Temperature	
4D.1.1	Operator adjusts the opening of ZC 201/202 once PAH 205 is activated Cooling system inspection is carried out	Operation Operation
4D.1.2	Operator adjusts the opening of ZC 201/202 once PAH 205 is activated	Operation
	2. Parameter Vibration	
4D.2.1	Operator adjusts the opening of ZC 201/202 once PAH 205 is activated	Operation
	NODE 6 & 7 LUBE OIL SYSYTEM	
	1. Parameter Pressure	
6.1.1	Always inspect the filter whenever PDIT 333 exceeds the setpoint	Maintenance
	Ensure the lube oil pump is turned off	Operation

The worksheet indicates that these risks could lead to significant consequences (refer to Table 3). Following this, a SIL (Safety Integrity Level) calculation was performed to assess the safety level of the ADB power generation unit. The results of this calculation can serve as a reference for improving the system's overall safety performance. Furthermore, the SIL calculations yielded the following results:

Table 14 Calculating Result SIL

NODE	POINT	LOCATION	SAFETY CONTROL	PFDavg loop	RRF	SIL
1	1	STEAM HEADER	PRESSURE HIGH	0.007	137.600	2
2	1	DEMISTER UNIT 1	LEVEL HIGH	0.016	62.711	1
	2	DEMISTER UNIT 1	LEVEL LOW	0.017	57.957	1
	3	DEMISTER UNIT 1	LEVEL HIGH HIGH	0.005	183.308	2
3	1	DEMISTER UNIT 2	LEVEL HIGH	0.016	62.711	1
	2	DEMISTER UNIT 2	LEVEL LOW	0.017	57.957	1
	3	DEMISTER UNIT 2	LEVEL HIGH HIGH	0.005	183.308	2
4	1	INLET TURBINE	PRESSURE HIGH HIGH	0.009	114.127	2
	2	TURBINE BEARING	TEMPERATURE HIGH HIGH	0.007	135.255	2
	3	TURBINE BEARING	VIBRATION HIGH HIGH	0.009	116.159	2
	4	TURBINE SPEED	SPEED HIGH HIGH	0.006	174.238	2
	5	GEARBOX	TEMPERATURE HIGH HIGH	0.007	135.255	2
	6	GEARBOX PINION	VIBRATION HIGH HIGH	0.009	116.159	2
	7	GENERATOR STATOR	TEMPERATURE HIGH HIGH	0.007	135.255	2
	8	GENERATOR BEARING	TEMPERATURE HIGH HIGH	0.007	135.255	2
	9	GENERATOR BEARING	VIBRATION HIGH HIGH	0.009	116.159	2
5	1	INLET TURBINE	PRESSURE HIGH HIGH	0.009	114.127	2
	2	TURBINE BEARING	TEMPERATURE HIGH HIGH	0.007	135.255	2
	3	TURBINE BEARING	VIBRATION HIGH HIGH	0.009	116.159	2
	4	TURBINE SPEED	SPEED HIGH HIGH	0.006	174.238	2
	5	GEARBOX	TEMPERATURE HIGH HIGH	0.007	135.255	2
	6	GEARBOX PINION	VIBRATION HIGH HIGH	0.009	116.159	2
	7	GENERATOR STATOR	TEMPERATURE HIGH HIGH	0.007	135.255	2
	8	GENERATOR BEARING	TEMPERATURE HIGH HIGH	0.007	135.255	2
	9	GENERATOR BEARING	VIBRATION HIGH HIGH	0.009	116.159	2
6	1	OUTLET LUBE OIL FILTER	PRESSURE LOW LOW	0.010	103.228	2
	2	LUBE OIL TANK	LEVEL LOW LOW	0.005	183.308	2
7	1	OUTLET LUBE OIL FILTER	PRESSURE LOW LOW	0.010	103.228	2
	2	LUBE OIL TANK	LEVEL LOW LOW	0.005	183.308	2
8	1	AUX COOLING WATER PUMPS	FLOW LOW	0.008	124.808	2

It can be observed that all evaluated nodes fall under SIL 2, indicating that the existing safety systems throughout the process are generally adequate and well-implemented.

5 Conclusion

The key findings of this study are as follows:

a. At the Ulumbu Geothermal Power Plant, particularly in Units 1 and 2, medium-level risks were identified. If the defined failure scenarios occur, they could result in substantial consequences.

b. The SIL analysis shows that the safety integrity level across the evaluated nodes is at Level 2, suggesting that the safety protection systems currently in place are sufficiently reliable.

c. Based on the author's observation, it is recommended to install an additional Shut-Down Valve at the end of the steam header. This valve would serve as a protective measure in case the rupture disk in the steam gathering system is triggered, thereby minimizing the resulting impact or damage.

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