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A Review: Reliability Assessment of Isolated Phase Busduct Through FMEA and RCFA Methodologies

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Abstrak

Penelitian ini mendiskusikan kehandalan *Isolated Phase Busduct* (IPB) unit pembangkit panasbumi masih perlu ditingkatkan karena gangguan-gangguan yang sama masih terjadi, dimana pada periode tahun 2018-2023 gangguan tersebut telah menyumbangkan *Loss Production Opportunity* sekitar 65 Miliar Rupiah. Oleh karena itu penelitian ini akan memberikan usulan atau saran faktor apa saja yang perlu ditingkatkan agar kehandalan IPB disetiap unit pembangkit listrik panasbumi meningkat. Adapun metode yang digunakan dalam penelitian ini adalah *Failure Mode And Effect Analysis* (FMEA) dan metode *Root Cause Failure Analysis* (RCFA), dimana FMEA membantu dalam mengidentifikasi potensi kegagalan dan menentukan prioritas mitigasi dan menentukan nilai *Risk Priority Number* (RPN), *Root Cause Failure Analysis* (RCFA) mengungkap penyebab utama kegagalan yang telah terjadi, dari kedua metode tersebut diketahui bahwa gangguan yang terjadi sebenarnya dapat diidentifikasi lebih dini sebesar 91,2% serta faktor seperti *manufacture design, aging equipment, unproper installation, Lack Quality Control*, dan *unproper mobilisation* harus dieliminasi dalam upaya meningkatkan kehandalan IPB dimana faktor-faktor tersebut harus diperhatikan dari mulai fase proyek sampai dengan fase operasional.

Kata kunci: *Failure Mode and Effect Analysis, Isolated Phase Busduct, Risk Priority Number, Risk Priority Number*

Abstract

This research discuss the reliability of the Isolated Phase Busduct (IPB) geothermal generating unit still needs to be improved because the same disturbances still occur, where in the 2018-2023 period these disturbances have contributed to a Loss Production Opportunity of around 65 billion rupiah. Therefore, this research will provide suggestions or suggestions for what factors need to be improved so that the reliability of IPB in each geothermal power plant unit increases. The methods used in this research are failure mode and effect analysis (FMEA) and the Root Cause Failure Analysis (RCFA) method, where FMEA helps in identifying potential failures and determining mitigation priorities and determining the value of the Risk Priority Number (RPN), Root Cause Failure Analysis (RCFA) reveals the main causes of failures that have occurred, from these two methods it is known that the disturbances that occur can actually be identified earlier by 91.2% as well as factors such as manufacture design, aging equipment, improper installation, Lack of Quality Control, and inappropriate mobilization must be eliminated in an effort to increase IPB's reliability where these factors must be considered from the project phase to the operational phase.

Keywords: Failure Mode and Effect Analysis, Isolated Phase Busduct, Risk Priority Number, Root Cause Failure Analysis

1. Pendahuluan

The dependability of electrical systems is a critical factor in industrial operations, particularly for firms within the energy industry. The Isolated Phase Busduct (IPB) serves as a critical component in electricity distribution, significantly contributing to the reliability and efficiency of power flow in power plants (Maletič et al., 2020). IPB is a sealed electrical conduit engineered to mitigate current leakage, improve safety, and diminish the likelihood of external disturbances (Hajiagha et al., 2016). The persistent increase in electricity consumption has rendered the reliability of IPB a major consideration for energy firms, particularly geothermal power plants. This system possesses several exceptional attributes, including robust physical insulation, wherein the conductors within the busduct are encased in materials capable of withstanding high voltages and safeguarding against external interference(Li et al., 2024).

The employed insulation materials and construction design can mitigate the risk of corrosion and damage, hence influencing power flow quality and performance. In high-power applications, IPB is frequently utilized in systems handling currents above 1000A, establishing it as the preferred option in industrial electrical systems and power plants(Siva Sathyanarayana & Amarnath, 2012).

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Prior scholars have undertaken multiple investigations into the reliability of IPB, including a pertinent study that analyses the impact of IPB design on the efficiency and stability of electrical systems. The research indicated that employing superior materials and ideal design enhances the longevity of IPB against electrical and environmental disruptions (Al Marzooqi et al., 2019; Alsyouf et al., 2021). Additional research underscores the significance of predictive maintenance through sensor technologies and data analysis to identify potential damage to IPB at an early stage(Fu et al., 2024). The utilization of technology for forecasting disruptions is prevalent; yet, its effectiveness and accuracy in IPB remain contentious issues.

Consequently, additional research on the execution of a comprehensive IPB reliability enhancement approach across all power plant units remains constrained. Most prior research has concentrated on certain elements, such as design or maintenance, without synthesizing them into a cohesive framework. Furthermore, research addressing particular conditions in Indonesia, including the humid tropical environment and seismic activity, has yet to be undertaken, as it has predominantly concentrated on general specifications. This technique aims to identify the fundamental causes of the difficulties with greater precision and to deliver more effective and efficient remedies.

2. Method

2.1. Research Flowchart

The process and stages of this research are identifying IPB failures, creating an FMEA including IPB RPN, creating an IPB RCFA, and drawing conclusions and suggestions. See Figure 1 for more information of the proposed methods using research's flowchart.

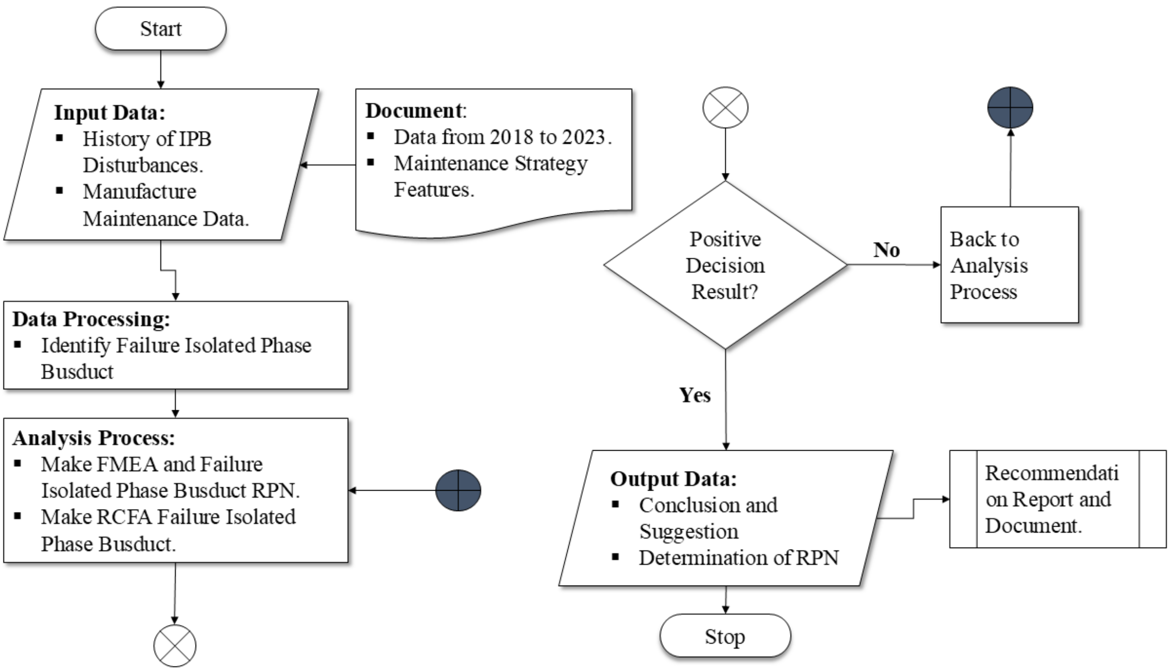

Figure 1. Research Flowchart Analysis Process

Figure 1 shows the sequence of analytical processes performed to determine the value and technical recommendations resulting from isolated phase busduct (IPB) failures, generally shown in high-voltage power grid systems, especially in large power plants and industries. Various analytical methods were considered to provide efficiency and recommendations for system damage that were deemed appropriate based on existing procedures.

In this study, FMEA is needed as an analysis process for determining the list of causes of failure, so that identification will be more focused with RCFA as a supporter in the value that will be selected at RPN. The root of the problem will probably be more reviewed from the type of Man Power, Maintenance Management, Material (eg; Aging, etc.) (Dolin, 2020). The next step is data processing based on reference/assessment guidelines analysed based on FMEA and RCFA(Kim & Zuo, 2018). The next stage is data processing. This paper describes the data examination process that is carried out as an identification step for deficiencies that may arise in IPB failures. The steps for identifying IPB weaknesses are obtained from existing data which are then analyzed for system failures. This identification also helps the assumptions underlying the system failure. Then, the examination of each failure is finalized using two powerful methodologies, namely Failure Modes and Effects Analysis (FMEA) and Risk Priority

Number (RPN) assessment (Eyuboglu et al., 2020). FMEA method is an instrument to identify the possibility of many failures in the IPB system and the possible impact on system performance. Each failure mode is evaluated based on how often it occurs, the severity of the impact, and the ease of investigation in calculating the RPN value. The numbers obtained will indicate the priority in management. Meanwhile, to determine the main cause of failure in this system, a Root Cause Failure Analysis (RCFA) technique cannot be separated from the activity. RCFA has the ability to examine the root cause and is a prevention strategy against further failure(Wang et al., 2021).

After the analysis procedure, evaluation is the finalization activity to be carried out. If the analysis results indicate that the problem can be handled properly, follow-up actions will be used. However, if the results of the problem are not found, then it will return to the analysis method to obtain an effective and efficient solution. This step consists of references made to changes in maintenance methods and/or a repair activity that helps reduce the likelihood of subsequent disruptions occurring. The RPN assessment of failure can be determined based on a priority scale against the level of risk posed. So, in the end, the results of the analysis and recommendations are suggested as one of the maintenance strategies that need to be considered as proposals, and steps taken in preventing a decrease in the reliability of the IPB system that will be implemented by relevant stakeholders in improving and maintaining the electrical system.

2.2. Identification of IPB Disorders

The collection of historical information data, including IPB disruption data and minutes from reliable sources must be correct and precise(Lu et al., 2021), Refer to the information in the IPB fault table to help identify the estimated fault and its root cause or problem.

2.3. Determination of Failure Mode and Effect Analysis (FMEA)

Engineering methods for identifying and minimizing potential defects. FMEA is used to prevent failures that might harm the company monetarily and reputationally(Patil et al., 2022). This aspect contributes to system failures due to IPB disturbances, since the failure to identify equipment malfunctions early precludes the establishment of an appropriate maintenance strategy, leading to unforeseen operational failures (Hatala et al., 2023). FMEA is a straightforward, rapid, and efficient instrument for evaluating success and safety; yet, it is constrained by its reliance on comprehensive data. The constraints of FMEA become evident when used to new systems lacking comprehensive risk data (Mzougui & El Felsoufi, 2019).

2.4. Determination of Risk Priority Number (RPN) Value

Subsequent to executing the stages utilizing the FMEA methodology, the following action is to compute the value of each RPN (Kamble & Rajiv, 2022), defined as the product of Severity (S), Occurrence (O), and Detection (D), as articulated in Eq. (1):

$$RPN = (S)\ x\ (O)\ x\ (D) \tag{1}$$

Equation (1) indicates that the RPN value is derived from the multiplication of the severity value, incidence value, and detection value, which have been established according to the risk values in Table (1). Severity is an evaluation of the extent of the impact that may arise from a failure. The evaluation scale typically ranges from 1 to 10, where 1 signifies negligible and 10 denotes disastrous. Occurrence: Evaluates the frequency with which the failure cause is expected to arise. The evaluation scale generally ranges from 1 to 10, with 10 signifying a high probability of failure. Detection: Evaluates the extent to which the failure's cause may be identified. The evaluation scale generally ranges from 1 to 10, with 10 signifying a markedly low detecting capability.

2.5. Determination of Root Cause Failure Analysis (RCFA)

This is a method for determining the causes of failure in a system or process. The goal of RCFA is to avoid repeating the same failure in the future. Understanding the core reasons of failure may help companies improve efficiency, quality, and safety(Patil & Bewoor, 2021). The purpose of RCFA is to discover the root cause of an issue, rather than only addressing the obvious symptoms, guaranteeing that the selected cure prevents the recurrence of the same problem.(Sheng et al., 2023).

The first step of RCFA is gathering relevant information about the failure, including as data from incident reports, system assessments, maintenance documents, and other materials that might shed light on the system's status at the time of failure (Patil et al., 2021). Create a detailed problem definition based on the evidence obtained. This encompasses delineating the extent of the failure, its ramifications, and the circumstances and setting in which the failure transpired. Employ several analytical tools to analyze probable underlying causes, such as the five whys analysis, which requires asking "Why?" five times to identify the core reason, and the FMEA, which is used to outline future failures, their repercussions, and their recurrence rates (Petrescu et al., 2021).

3. Result and Discussion

3.1. Disturbance Identification of IPB

Table 1 explains the data taken from 2018 – 2023, where from the data it is known that several units have a history of disruption and Loss of Production Opportunity (LPO), from this further assessment and analysis are carried out and explained in the following sub-chapters. See table 1.

Table 1. Existing Disturbance Data (2018 - 2023)

No	Unit	Year	The Root Cause of Disorders	Duration (day)	LPO (billion Rp)
1	I	2022	Micro void in resin Phase S	12	23.4
		2023	Water ingress tubular sleeve Phase S	4	7.20
2	II	2022	Water ingress tubular sleeve Phase S	5	5.80
3	III	2019	Water ingress tubular sleeve Phase T	13	10.1
		2023	Water ingress tubular sleeve Phase S Micro void in resin Phase R Aux Transformer	7	2.60
4	IV	2018	Micro void in resin Phase S	14	9.90
		2020	Water ingress tubular sleeve Phase S & T	3	2.20
5	V	2019	Material damage & Micro damage main sleeve phase S	5	3.80

Table 1 shows the disruptions that occurred in IPB from 2018- 2023, along with the principal reasons, duration of each disruption, and related LPO in billions of Rupiah (Rp). This table contains important information about the frequency and impact of disturbances on the IPB system used in electricity distribution. This table provides identification of all the main causes of problems that often arise during the period, and the component part of the Tubular sleeve water ingress is the most loyal of the possible failures. Furthermore, the part of Micro cavity in resin and Material damage in the main sleeve are in the next vulnerable position. The distribution shows that the tubular sleeve water ingress is the main cause in various units, including Unit I (2023), Unit II (2022), Unit III and Unit V (2019). This shows that water loss or penetration into the sleeve is the main root that has a direct impact on the performance of the IPB over this time span. Micro voids in the resin are also a common source of distress, see columns in Units I (2022), IV (2018), and V (2019). Concerns have been raised about the cause of micro void issues in insulation resins. This will result in decreased effectiveness of the insulation layer and electrical failure. Material failure & micro-damage in the main sleeve occurred in Unit V (2019), this data displays the material degradation in the main sleeve which has a direct impact on the mechanical strength and reliability of the power system.

The duration of existing faults ranges from 3 to 14 days in Unit III in 2023. This unit experienced a longer disruption of 13 days due to water infiltration into the Phase T tubular sleeve. This indicates that the disruption was caused by water infiltration, which of course results in considerable downtime, thus directly affecting operating costs. On the other hand, Unit II (2022) and Unit V (2019) experienced shorter disruptions, with 4 days and 5 days respectively. Although the failure duration decreases, the underlying reason, is the presence of micro cracks in the resin and degradation of the material, this becomes important and requires inspection activities and preventive measures to prevent further failures. The LPO in this table has a fluctuating value according to the duration of the fault and its impact on system operation.

LPO in each unit shows that Unit I (2022) experienced the largest operational loss of IDR23.4 billion, where micro voids in the Phase S resin and suspension for 12 days were the main causes. This loss emphasizes that disruptions to the insulation system can substantially affect the operation of the IPB value. Unit III (2019) experienced the second largest substantial loss of IDR10.1 billion due to water intrusion in the Phase T tubular casing, this disruption caused the system to be inoperative for 13 days. The extended period of disruption resulted in considerable losses. Unit IV (2020) and Unit V (2019) experienced reduced losses, totalling Rp 9.90 billion and Rp 3.80 billion, respectively, despite having shorter periods of inactivity. This suggests that although disruptions were rectified more swiftly, the nature of the damage, such as material damage, can affect operational expenses. On the basis of conversations with reliable sources, it would appear that the maintenance of the IPB has been based on the guidelines provided by the Original Equipment Manufacturer (OEM). There are no preventative maintenance actions that take place while the unit is in operation, as stated in the guidelines for maintenance provided by the manufacturer. IPB maintenance is considered to be free maintenance. The following is a comparative analysis of the parameters given in the table is the IPB demands no routine maintenance. This signifies that the design and components of the Isolated Phase Busduct are adequately reliable and insulated, hence obviating the need for frequent maintenance over the long term. This maintenance-free feature results in lower operational expenditures since it removes the need for scheduling or additional costs connected with routine maintenance. Nonetheless, while normal maintenance is avoided, frequent inspections are still required to detect any damage that may affect the system's efficiency and dependability. When dust or filth accumulates on the IPB's bus bar, the manufacturer recommends cleaning it with soapy water, spirit, or alcohol. This confirms that component cleanliness is important, especially in the prevention of pollutants or debris that interfere with electrical conductivity or insulation values. The use of chemicals such as alcohol is one measure to remove small particles without affecting the insulation strength. The act of maintaining the cleanliness of electrical components will ensure optimal performance. The table explains that more maintenance is not required. It shows that IPB components are designed to work with little intervention or additional maintenance after the first installation, provided they are used appropriately and with proper technical references. This further substantiates that the IPB design is exceptionally durable and dependable, hence significantly enhancing efficiency in minimizing maintenance expenses related to component failure.

Table 2 explains the aspects of maintenance of the Isolated Phase Busduct (IPB) system based on the manufacturer's guidelines, which are regulated in several parameters covering IPB maintenance, handling if there is dust on the bus bar, and other maintenance.

Table 2. Manufacturer Maintenance Information

No	Parameter	Information
1	IPB Maintenance	Maintenance free
2	If bus bars is Heavy Coated with dust	Cleaning with soap water, spirit or alcohol
3	Other Maintenance	Not necessary

Despite the OEM IPB indicating that maintenance is complimentary, each unit's maintenance staff has devised a maintenance strategy, as illustrated in Table 3. Each unit has a different maintenance strategy for each IPB due to different manufacturers, resulting in a lack of comprehensive data and a lack of correlation between the maintenance teams of each unit. Therefore, a uniform maintenance strategy is needed that accommodates various IPB brands.

Table 3. Maintenance Strategy

Unit	Online Maintenance Strategy		Offline (for 4 Year)
	Checking activities	Duration	
I	▪ Visual Check	once a year	Visual Inspection Electrical Testing (IR, PI, Contact Resistance)
II	▪ Visual Check ▪ IR Thermography	once a year once a year	-
III	▪ Visual Check ▪ IR Thermography	once a year twice a year	Visual Inspection Electrical Testing (IR, PI, Contact Resistance, tan Delta)
IV	▪ Visual Check ▪ IR Thermography	4 times a year 4 times a year	Visual Inspection Electrical Testing (IR, PI, Contact Resistance, tan Delta)
V	▪ Visual Check ▪ IR Thermography ▪ PD bi-phase coupler	twice a year twice a year twice a year	Visual Inspection Electrical Testing (IR, PI, Contact Resistance, Hi-pot)

Table 3 presents a summary of the IPB maintenance plan, categorized into two primary types: online maintenance and offline maintenance, each having distinct periods for every unit. This table delineates the inspection operations conducted on each IPB unit, including the duration of the inspections and the offline maintenance actions performed every four years. This online maintenance is proposed to monitor and identify possible disturbances or possible damage without having to stop production completely. The maintenance procedure data contained in table 3 shows that Unit I is visually inspected once a year, the unit is limited to an annual visual inspection. This shows that the IPB system or its components in this unit are more preventable and require less maintenance. In Unit II, in addition to visual inspection, IR Thermography is used as a form of visual inspection to detect heat gain due to electric fields without requiring great effort. All of these Units ultimately require intense and continuous supervision. Unit III shows a more regular type of maintenance compared to other Units, with sufficient intensity, namely thermal inspection activities are carried out twice a year. This emphasizes the need for increased monitoring in this unit, thermal investigation treatment of anomalies is needed for early detection. Unit IV has the highest maintenance frequency, with thermal detection carried out every week. This has the potential that failure will be more severe if the inspection treatment is longer, which ultimately prevents preventive measures and the recovery process will be long (because failure) is not immediately prevented. This indicates that Unit IV has increased complexity or vulnerability, demanding close monitoring to detect problems early and avoid major operating interruptions. Unit V requires extremely complicated maintenance, including a bi-phase PD coupler for monitoring reasons. This suggests that Unit V may use more modern technologies or be more sensitive to subtle electrical faults, such as coupling component breakage or phase two disturbances.

3.2. FMEA Determination Result

As of now, none of the operating units possess the most recent IPB Failure Mode Effect Analysis (FMEA) based on the discussion outcomes. This aspect contributes to recurrent failures due to IPB disturbances, as the lack of re-evaluation of the FMEA since the initial incident precludes the establishment of an effective maintenance strategy, leading to unforeseen operational failures.

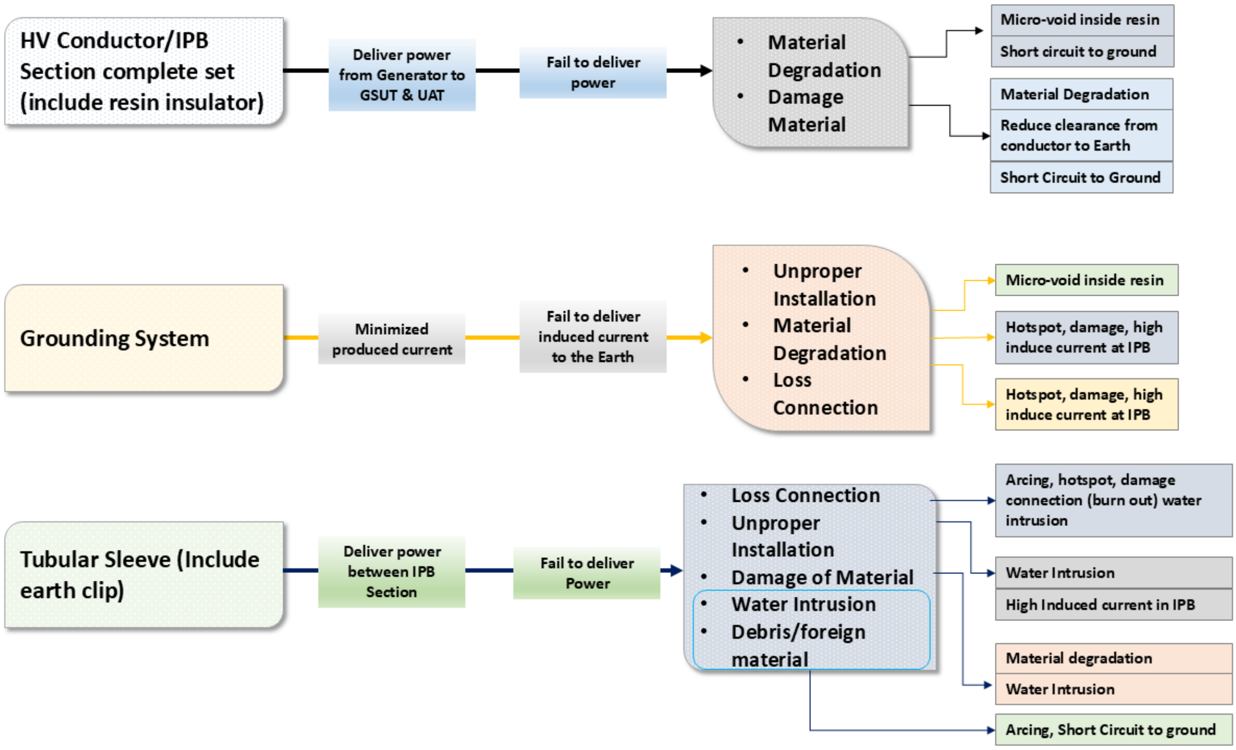

Figure 2. Isolated Phase Busduct using FMEA

The figure 2 shows the FMEA for the IPB system, focusing on potential failure modes across three major components: the HV Conductor/IPB Section (including resin insulator), Grounding, and the Tubular Sleeve (including earth clip). It illustrates the systematic approach for identifying and mitigating failure risks based on operational flow, material degradation, and installation errors. The initial element of the flowchart analyses the HV Conductor/IPB section, encompassing resin insulation, and its essential function in transmitting power from the generator to the Grounding Switch Unit (GSU) and Unit Auxiliary Transformer (UAT). The procedure commences by evaluating material degradation, which may lead to substantial failure. The existence of tiny voids inside the resin, which causes a short circuit to ground, is a major contributor to material deterioration in this context. The consequences of such deterioration may cause harm to the materials used, reducing their insulating properties and overall system performance. The following failure mechanism involves material deterioration, which is often caused by reduced clearance between conductors and the Earth, resulting in a short circuit to ground. If these mistakes are not addressed promptly, they can cause significant system instability and downtime. Effective maintenance and monitoring are critical for recognizing material degradation and preventing breakdowns from becoming more severe.

The second critical feature of the flowchart is grounding, namely its function in decreasing induced currents and permitting the safe dissipation of current to the Earth. When the device fails to send the generated power to Earth, a variety of problems might develop. Inadequate installation of grounding components can lead to material degradation, increased risk of disconnection, and improper grounding connections, resulting in inefficient power transmission. The failure modes underscore the need of proper grounding installation in ensuring the system's dependability. Potential difficulties, such as water penetration and higher induced currents in the IPB, exacerbate the damage. Correcting the placement of grounding systems can significantly lessen these hazards. The final component focuses on the tubular sleeve, which is necessary for transporting power between IPB segments. Failures in this context include disconnections and faulty installations. Inadequate installation or degraded components impair the system's integrity, cause water penetration, and allow unwanted debris to enter the system, reducing its dependability and performance significantly. Water penetration is acknowledged as a key cause of failure, exacerbating other failure modes such as material degradation and short circuits.

Water ingress into the IPB section can damage the resin, ruin the insulation, and cause irreparable damage to the equipment if not promptly investigated and repaired.

3.3. RPN Determination Result

According to the RPN statistical data, failure modes with high RPN values, specifically resin damage and water leakage, should be addressed with preventive maintenance and early detection measures. The RPN can be minimized by improving detection capability and lowering failure frequency through design improvements, using reliable materials, and increasing inspection schedules. In addition, failure modes with low risk significance scores or infrequent occurrences (e.g., grounding failures), can be given lower priority for routine maintenance. Nevertheless, these components are important for inspection activities to prevent more serious damage.

Table 4. Nilai Risk Priority Number (RPN) Determination Result

Potential Failure Mode	Potential Cause	S	O	D	RPN	Relative (%)	History of Disorders
Material Degradation	Micro void inside resin	8	7	7	392	13.2	√
	short circuit to grounding	8	5	6	240	8.10	√
	Hotspot, Damaged part, High induced current in IPB	8	5	5	200	6.70	√
Damage Material	Material Degradation	6	4	8	192	6.40	√
	Reduce clearance from conductor to Earth	6	5	6	180	6.00	√
	short circuit to ground	7	7	7	343	11.5	√
Loss Connection	Hotspot, damaged part, High induced current in IPB	4	5	5	100	3.40	-
	Arcing, Hotspot, Connection Damage (burn out), Water Intrusion.	5	5	5	125	4.20	-
Unproper Installation	Water Intrusion	8	8	7	448	15.0	√
	High induced current in IPB	6	5	7	210	7.10	√
Water Intrusion	Arcing, short circuit to ground	8	8	8	512	17.2	√
Debris/Foreign material	Arcing, short circuit to ground	3	3	4	36	1.20	-
Total					2978	100	91,2%

Table 4 indicted the RPN calculations for various failure modes of the IPB, based on the parameters of Severity (S), Occurrence (O), and Detection (D). The RPN values are obtained by multiplying these three parameters, each rated on a scale from 1 to 10. The table also includes the Relative (%) values that indicate the contribution of each failure mode to the total RPN, as well as the history of disorders associated with each failure mode. Material degradation shows relatively high RPN values, especially for micro void inside resin (392), which indicates a significant risk if degradation occurs in vital components like resin. This failure mode has high severity (8), a moderate occurrence rate (7), and is difficult to detect (7). Other causes, such as short circuit to grounding and hotspot in material, produce lower RPN values but still represent considerable risks. The history of disturbances indicates that material degradation has occurred previously, requiring preventive maintenance and repair actions to prevent further damage. The material damage exhibits a significant RPN value for short circuit to ground (343), signifying that this failure mode is extremely important and warrants prioritization. The causes are evident, including material degradation and incorrect installation; nevertheless, the severity (6) is less pronounced in comparison to material degradation. The history of disruptions reveals previous instances of material deterioration, requiring more frequent inspections and repairs to prolong the system's longevity. The loss of connection exhibits comparatively lower RPN values than other failure types; yet, it remains a potential concern. The occurrence of hotspots and damaged components can compromise system reliability, albeit infrequently. This failure mechanism requires attention, despite its lower significance compared to water intrusion. Inadequate installation demonstrates a considerable RPN value. Failures resulting from water incursion and elevated induced current in the IPB pose dangers to the system. Although the incidence rate is reduced (occurrence 5), failures resulting from installation errors may cause enduring complications in the electrical system, necessitating remedial measures. Water intrusion possesses the highest RPN value among all failure modes, signifying a substantial risk to the system. Water penetration can undermine insulation integrity and lead to short circuits or damage to essential components inside the system. The severity (8) and incidence (8) rates of this failure mode designate it as the highest priority for preventive measures and maintenance to avert significant repercussions. Debris or foreign material possesses the lowest RPN value; yet, it remains a worry, albeit less frequently. The likelihood of arcing or short circuits due to the intrusion of extraneous materials into the system is comparatively diminished. Notwithstanding the reduced RPN, it necessitates oversight to prevent possible system interruption. Of the 100% Relative Value available, there was an 8.8% reduction due to loss connection and debris/foreign material, resulting in a total of 91.2%.

3.4. RCFA Determination Result

Based on IPB's data on disruptions, most of the causes of disruptions were water ingress (5 times) and micro voids/decreased insulation of busducts (4 times). Using 5-Why analysis, we were able to identify the root causes of busduct failures in all operating units. The table 5 illustrates the 5-Why Analysis for the Isolated Phase Busduct (IPB) system and its failure modes, particularly focusing on issues such as water ingress in the sleeve, damaged gasket, loose bolt connections, and shorts to body or ground. This method is an appropriate technique in solving problems systematically, especially to identify the root cause of failure by asking "why" in succession to identify the problem to its roots. The main source of water entering the casing was identified as the absence of a blocking cover component and resulted in the failure. The lack of the flange cover is due to the part being missing since the Engineering, Procurement, Construction, and Commissioning (EPCC). The third explanation is that the component was not installed owing to an erroneous installation during the EPCC phase. The fourth inquiry finds that the presence of inexperienced people during the EPCC exacerbated the problem, while the fifth inquiry identifies the root cause as poor-quality control during the EPCC phase. The cascade "why" analysis reveals that the failure's root cause is poor management and training during the installation phase, resulting in missing components that jeopardize the system's integrity.

The damaged gasket indicates the primary cause, which is the deterioration of aging equipment. The gasket degradation is attributable to natural wear and tear, characteristic of aging equipment. Thirdly, there is no additional inquiry into the secondary or tertiary stages of this failure cause, as the deterioration of equipment is a predictable and inevitable concern. The fourth and fifth Why indicate that no additional study is necessary, as this pertains to routine maintenance and equipment lifecycle issues. The issue of aging equipment suggests that maintenance methods must be evaluated to anticipate wear and tear, ensuring that preventive measures are implemented during both the design and operating phases.

Table 5. IPB Failure Analysis using 5th step "*Why*"

Why				
1st	2nd	3rd	4th	5th
Water Ingress in Sleeve	Missing Component (flange cover)	Part was missing since EPCC	Lack QC during EPCC	-
		Unproper Installation	Unskill person during EPCC	Lack QC during EPCC
	Damaged Gasket	Aging Equipment	-	-
	Loose bolt Connection	Unproper Installation	Unskill person during EPCC	Lack QC during EPCC
		Unproper Installation	Unskill person during EPCC	Limited person from OEM
		Operating Aging	-	-
Short to Body/ Ground	Crack Micro Void / in insulation	Unproper Mobilisation	-	-
		Unproper Installation	Lack QC During EPCC	
		Manufacture Defect	-	-
	Water Ingress in sleeve	"See Above"	-	-
Humidity	Desiccant Bag Saturated	Lifetime	-	-
	No Heater	Manufacture design	-	-

The loose bolt connection represents a failure mode associated with inadequate installation. The second reason indicates that the poor installation resulted from untrained staff during the EPCC. The third inquiry indicates that the deficiency in unskilled labour was again attributed to insufficient quality control during the Engineering, EPCC phase. The fourth inquiry reveals an additional factor of inadequate staff from the OEM, signifying that the OEM team failed to supply sufficient resources or appropriate training during the installation process. This failure pattern highlights the significance of good installation and a proficient staff, emphasizing the necessity of personnel skill levels and quality control inspections during important phases such as installation.

Short circuit to the body/ground shows the main cause: Micro-gaps in insulation, which cause short circuits, are mostly caused by insufficient mobilization during installation. The second is that inadequate mobilization resulted from substandard installation procedures, which compromised the efficacy of the insulation. The third piece of evidence is that incompetent installation personnel during the setup process is another cause. The problem was compounded by inadequate quality control during the EPCC phase and certain manufacturing defects. Micro-gaps that cause serious and urgent short circuits in the installation procedure, especially in the assurance that the insulation is installed and carried out with appropriate repair procedures.

The 5-Why analysis provides a clear working guide for understanding the various failure modes of IPB systems. The main findings lie in inadequate installation and professional staffing is an actual issue, the need for improved training and quality, during critical periods of installation and maintenance. Material deterioration, damage to gaskets and insulation, should be considered in predictive maintenance activities to reduce equipment aging. Lack of quality control during EPCC was highlighted as a root cause of failure, emphasizing the need for strict quality assurance methods throughout the engineering, procurement and construction stages. Insufficient resources or inadequate training by OEM personnel were major concerns, indicating that OEMs should take a more proactive approach to guarantee proper installation and maintenance of equipment.

3.5. Analysis Result and Recommendations for Improvement

Historically, increased frequency of online maintenance has been associated with increased system complexity and vulnerability to disruption. Units IV and V require more frequent maintenance and a wider range of inspections than other Units, as they may operate under more severe conditions or be more susceptible to failure. The four-year offline maintenance activity step indicates that, while routine inspections are performed, detailed assessments are still required to ensure the optimal condition of the IPB system at all times. This offline maintenance can reduce the likelihood of serious damage and extend the system's overall operating life. The maintenance conducted on Units IV and V indicates a system characterized by greater complexity and reliability, whereas Unit I is less complex and necessitates maintenance less frequently.

The assessment results in this paper show the importance of risk management in IPB. Concentrating on failure modes with high RPN values is expected to result in more effective handling improvements, avoid substantial damage, and save downtime and maintenance operational costs in the long term. According to the RPN calculation results, water infiltration (512) is the highest risk failure mode that requires the most attention, followed by material damage (392) and damaged material (343). Although there are many failure modes with lower RPN, such as lost connections and debris, these modes must still be addressed to minimize the risk of more severe disruptions and maintain reliable system performance. The implementation of preventive maintenance activities is suggested to be better as early inspections according to RPN values eliminate damage. The FMEA results highlight critical areas for improvement in the IPB system, in training, quality assurance, and preventive maintenance strategies. By addressing these root causes, businesses may significantly reduce the frequency of outages and increase the reliability of their electrical systems.

Conclusion

Based on the observations and research undertaken at IPB across several geothermal power facilities, the following findings were reached:

1. Each unit employs a distinct maintenance approach for each IPB based on varying manufacturers, leading to an absence of complete data and a disconnection among the maintenance teams of each unit. Consequently, a standardized maintenance plan that encompasses several IPB brands is required.
2. The FMEA approach requires revision following the initial occurrence to reassess maintenance methods and avert recurrence of similar events.
3. The correlation of data in FMEA, RPN, and RCFA indicates that 91.2% of IPB disruptions can be effectively identified by the FMEA approach, based on the findings of the RCFA methods.
4. The FMEA and RCFA analyses indicate that factors to be addressed from the initial project phase to the operational phase, as well as the primary root causes to be eradicated to enhance IPB reliability, encompass manufacturing design, aging equipment, improper installation, insufficient quality control during EPCC, limited OEM personnel, and inadequate mobilization.

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