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Analysis of System Reliability at Public Electric Vehicle Charging Stations (SPKLU) Using Failure Mode and Effect Analysis and Reliability Block Diagram Methods

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***Abstract* - The transition towards an electric vehicle ecosystem represents a strategic approach to mitigating greenhouse gas emissions from the transportation sector. The success of this transition is highly dependent on the availability and operational reliability of Public Electric Vehicle Charging Stations (SPKLU). This study aims to evaluate the reliability level of the SPKLU system and determine the optimal maintenance intervals by integrating the Failure Mode and Effect Analysis (FMEA) and Reliability Block Diagram (RBD) methods. Qualitative analysis through FMEA indicates that operational failures are primarily driven by short circuits, overheating, extreme weather conditions, physical impacts, and component corrosion. Based on the Risk Priority Number (RPN) calculations, the charging cable and connector, surge protection, circuit breaker, and power contactor are classified as the most critical components. Furthermore, quantitative modeling utilizing the RBD method with a series configuration yields partial reliabilities of 50.00% for the charging subsystem, 36.78% for the control and monitoring subsystem, and 67.36% for the communication subsystem. Consequently, the overall reliability of the SPKLU system is critically low at 12%. To minimize downtime and prevent unexpected breakdowns, this study recommends implementing preventive periodic maintenance every 156.084 hours for the charging subsystem, 181.678 hours for the communication subsystem, and 218.518 hours for the control and monitoring subsystem.**

Keywords: SPKLU, System Reliability, Failure Mode and Effect Analysis (FMEA), Reliability Block Diagram (RBD), Maintenance Interval.

I. INTRODUCTION

Air pollution and global warming have emerged as critical global environmental challenges, primarily driven by greenhouse gas emissions from the transportation sector. In developing nations such as Indonesia, this issue has reached an alarming level [1]. Data from the Ministry of Environment and Forestry indicates that the transportation sector is the largest contributor to air pollution in the Jabodetabek region, accounting for 44% of total emissions, followed by the energy industry (31%), manufacturing industry (10%), residential sector (14%), and commercial sector (1%). To mitigate these environmental impacts, the transition towards Electric Vehicles (EVs) has become a strategic priority [2]. The Indonesian government is actively working to accelerate EV adoption, including through plans to mandate the use of EVs as the primary mode of transportation in the Nusantara Capital City (IKN).

Nevertheless, the widespread transition toward electric vehicles is still constrained by several technical and economic factors. Research by the Institute for Essential Services Reform (IESR) indicates that high initial investment costs, limited driving range, long charging times, and insufficient charging infrastructure are the main barriers to adoption [3].

Therefore, the availability and operational assurance of Public Electric Vehicle Charging Stations (SPKLU) serve as a fundamental prerequisite for supporting the electric vehicle ecosystem [4]. This operational assurance relies heavily on the system's reliability level. As defined by O'Connor and Kleyner, technical reliability is the probability that a device will function without failure under specified conditions for a certain duration [5]. Since SPKLU operates continuously with high current loads, meeting these reliability standards necessitates an evaluation of each supporting component to mitigate the risk of sudden failures.

As a practical measure to implement this evaluation and prevent unforeseen downtime, this research uses risk analysis modeling through Failure Mode and Effect Analysis (FMEA) and Reliability Block Diagram (RBD) methods[6][7]. In the initial phase, FMEA is used to map potential failure points within component specifications and assess the severity of the associated risks. Following this, the RBD method is used to model functional interactions between subsystems, enabling the probabilistic calculation of how an individual component's failure impacts the overall operational system [8]. Using the identified critical components and reliability probability values, a precise periodic maintenance schedule for SPKLU facilities can be formulated. This structured approach aims to minimize operational downtime and ensure the sustained stability of charging system performance [9].

II. RESEARCH METHODS

2.1 Literature Study and Observation

This research begins with a literature review to establish the theoretical foundation for electric vehicle charging systems and reliability engineering. Subsequently, empirical data processing is conducted by mapping potential failure modes within the Public Electric Vehicle Charging Station (SPKLU) units, identifying their functional failures, and analyzing the effects of these failures on the system's operational continuity.

2.2 Risk Assessment using FMEA

Following the mapping of failure modes, a risk assessment is applied to identify the critical components of the SPKLU. Critical components are defined as elements highly susceptible to failure, directly impacting the operational reliability of the entire system [10]. The identification of these components is determined quantitatively using the Risk Priority Number (RPN) within the Failure Mode and Effect Analysis (FMEA) framework. The RPN is calculated by multiplying three evaluation criteria: Severity (S), Occurrence (O), and Detection (D).

1. Severity (S) refers to the magnitude of loss or the extent of operational consequences resulting from a functional failure within the system.

Table 1: Risk Priority Number Severity [9]

Severity	Rank	Description
Dangerous Without Warning	10	The system is inoperative and failure of the system will result in very harmful effects to the user.
Very High	8	System is not operational
Medium	6	The system operates and is safe to use for a period of time but suffers performance degradation.
Low	4	Minor effect of degradation on system performance
Very Low	2	Negligible effect on system performance
No Effect	1	No effect

2. Occurrence (O) represents the frequency or the likelihood of a physical failure occurring within the system during its operational lifespan.

Table 2: Risk Priority Number Occurrence [9]

Occurrence	Rank	Description
Very High	10	Failure Occurs Frequently
Very High	9	Failure Occurs Frequently
High	8	Failure May Occur
High	7	Failure May Occur
Medium	6	Failure Rarely Occurs
Medium	5	Failure Rarely Occurs
Low	4	Very Minor Failure Occurs
Low	3	Very Minor Failure Occurs
No Effect	2	Almost No Failure
No Effect	1	Almost No Failure

3. Detection (D) represents the probability or capability of inspection instruments and operators to identify potential failures before their effects propagate throughout the entire system.

Table 3: Risk Priority Number Detection [9]

Detection	Rank	Description
Almost Impossible	10	Cannot detect
Very Remote	9	Failure occurs randomly
Remote	8	Failure detected after the process by visual or auditory inspection by the operator
Very Low	7	Failure detected by visual inspection or after the use of measuring instruments by the operator
Low	6	Failure detected after measurement process by operator
Moderate	5	Failure detected after the measurement process by the operator or in the unit by a control device on the unit, such as a light buzzer.
Moderately High	4	Failure detected after the measurement process by the operator or in the unit by a control device on the unit, such as a light buzzer.
High	3	Failure detected after the measurement process by the operator or in the unit by a control device on the unit, such as a light buzzer.

2.3 Statistical Analysis and Reliability Calculation

This stage is conducted after identifying the critical components of the SPKLU using the RPN method, followed by statistical calculations and testing. The steps include [11][12][13]:

1. Calculating the Time Before Failure
2. Calculating the Index of Fit
3. Selecting the Largest Index of Fit
4. Calculating the Selected Distribution Parameters

2.4 Reliability Block Diagram (RBD) Modeling

The final stage of this research involves constructing a system architecture model using the Reliability Block Diagram (RBD). The SPKLU system is broken down into its fundamental subsystems and components based on their respective functional interactions. By mapping these relationships particularly by accounting for the varying reliability values of each component the RBD method generates an estimate of the overall system reliability [14]. This probability calculation serves as a foundational reference for formulating precise preventive maintenance schedules and targeted corrective measures [15].

III. RESULTS AND DISCUSSIONS

3.1 Analysis of SPKLU Components Using the FMEA Method

This FMEA study is conducted to maintain the reliability of the SPKLU unit. This approach is based on the premise that any failure mode within a component can directly lead to system malfunction, making the early identification of risk factors imperative. The objective of applying FMEA is to establish measurable actions to address, eliminate, and mitigate potential failures identified during periodic maintenance. The risk management process using the FMEA method initiates with identifying risks across components that influence the reliability and operational performance of the SPKLU. This identification phase involves cataloging all potential failure risks for each respective component. The results of the SPKLU component analysis utilizing the FMEA method are presented in Table 4.

Table 4: Analysis of SPKLU Components Using the FMEA Method

Sub - system	Comp.	Failure Mode	Impact	Cause	Prevention
Charging	Surge Protection	Over heating	Surge block failure	MOV/semiconductor defect	Enclosure & cooling
	AC Circuit Breaker	Aging & Corrosion	Frequent tripping	Extreme temp/humidity	Visual/audio checks
	AC Power Contactor	Short Circuit	Collateral damage	Defective assembly/aging	Circuit protection & maintenance
	Cable & Connector	Open Circuit	EV charging failure	Wear, tear & assembly defect	Standard parts & inspection
Control & Monitor	Aux. Power Supply	Over heating	Control unit power loss	Cooling failure & dust	Standard parts & cleaning
	AC Controller	Overvoltage/ current	Internal circuit damage	Electrical overload	Circuit protection & maintenance
	Energy Measurement	Overcurrent & Corrosion	Inaccurate readings	Overload & environment	Circuit protection & maintenance
	Residual Current	Short Circuit	Leakage detection failure	Defective assembly/aging	Circuit protection & maintenance
Comm. & Interface	Connectivity Module	Connection Failure	Fails to connect EV/User	Physical module damage	Periodic maintenance
	Display & LED	Blank/ flickering	Operation hindered	Defective assembly/ environment	Circuit protection & maintenance
	RFID Sensor	Mech/Elec Failure	Fails to read tags	Extreme temp/humidity	Standard parts & installation

3.2 Analysis of SPKLU Critical Components Using Risk Priority Number Values

The Risk Priority Number (RPN) serves as a risk rating for each failure mode, calculated by multiplying three parameters: severity, occurrence, and detection. Table 5 presents the assessment of the critical SPKLU components based on these calculated RPN values.

Table 5: Analysis of SPKLU Critical Components Using Risk Priority Number Values

Component	Severity	Occurence	Detection	RPN
Surge Protection	10	2	6	120
AC Isolation Circuit Breaker	10	2	6	120
AC Power Contactor	10	2	6	120
Charging Cable & Connector	8	8	2	128
Auxiliary Power Supply	8	2	4	64
AC Charging Controller	8	2	4	64
Energy Measurement	6	2	4	48
Residual Current Monitor	6	2	4	48
Wired & Wireless Connectivity	5	8	2	80
Display & LED Indicator	2	8	2	32
Radio Frequency Identification	2	2	2	6

3.3 SPKLU Reliability Analysis

3.3.1 Sub-system Malfunction Time Calculation

This stage determines the Time to Failure (TTF), Time to Repair (TTR), and Time Between Failures (TBF) for each subsystem. Table 6 presents an example of the failure time calculations for the SPKLU charging subsystem.

Table 6: Example of data recapitulation of the results of the calculation of damage time in the charging sub-system of the SPKLU system

Downtime Started	Downtime Completed	TTR (hour)	TTF (hour)	TBF (hour)
09/01/2023 16.45	09/01/2023 19.55	3,167	-	-
14/02/2023 13.00	14/02/2023 16.49	3,817	857,083	860,250
18/03/2023 04.18	18/03/2023 08.40	4,367	755,483	759,300
22/03/2023 13.35	22/03/2023 17.42	4,117	100,917	105,283
29/05/2023 21.36	30/05/2023 07.16	9,667	1635,900	1640,017
15/07/2023 02.57	15/07/2023 10.20	7,383	1099,683	1109,350
02/08/2023 04.36	02/08/2023 09.15	5,350	426,267	433,650
01/10/2023 14.55	01/10/2023 20.16	5,350	1445,667	1450,317
06/10/2023 12.13	06/10/2023 15.34	3,350	111,950	117,300
01/11/2023 03.48	01/11/2023 09.21	5,550	612,233	615,583
12/12/2023 16.41	12/12/2023 21.46	5,083	991,333	1002,883
21/12/2023 23.22	22/12/2023 09.35	10,217	241,600	246,683

3.3.2 Index of Fit Calculation

The calculation of the Index of Fit serves as the preliminary identification stage to determine the statistical distribution model of the acquired data (in this case, the failure times within the subsystems). This calculation process utilizes the Least Squares Curve Fitting method. The statistical distributions evaluated include the Normal, Lognormal, Exponential, and Weibull distributions. The results of these Index of Fit calculations are presented in Table 7.

Table 7: The results of the recapitulation of the Index of Fit TBF of the charging sub-system

Sub- System	Distribution			
	Normal	Lognormal	Exponential	Weibull
Charging	0,9849	0,9544	0,9630	0,9764
Control & Monitor	0,9543	0,9564	0,9789	0,9441
Communication	0,9210	0,9580	0,9577	0,9278

3.3.3 Goodness of Fit Test

After calculating the Index of Fit for all subsystems, goodness-of-fit tests are conducted, prioritizing the statistical distribution that exhibits the highest coefficient value. The specific tests applied are as follows:

1. Mann's Test (α = 0.05) to evaluate the Weibull distribution.
2. Kolmogorov-Smirnov Test (α = 0.05) to evaluate the Normal and Lognormal distributions.
3. Bartlett's Test (α = 0.05) to evaluate the Exponential distribution.

Table 8: Recapitulation of Goodness of Fit Test for SPKLU System goodness of fit test

Sub-system	Initial Distribution Conjecture	Result	Subsequent Distribution Conjecture	Result	Final Decision
Charging	Normal	Accepted	-	-	Normal
Control & Monitor	Exponential	Accepted	-	-	Exponential
Comm.	Lognormal	Accepted	-	-	Lognormal

3.3.4 Calculation of Distribution Parameters

Parameter calculations for each location are based on the statistical distribution of the results from the Goodness of Fit test. The parameters for the charging sub-system with Normal statistical distribution are μ and σ. Table 9 shows a recapitulation of the SPKLU system distribution parameter calculations.

Table 9: Recapitulation of SPKLU System Distribution Parameter Calculation

Sub-system	Distribution	μ	σ	λ	s	tmed
Charging	Normal	758,286	571,428	-	-	-
Control & Monitor	Exponential	-	-	0,000642	-	-
Comm.	Lognormal	-	-	-	0,907	635,704

3.3.5 Mean Time Before Failure Calculation

Mean Time Before Failure (MTBF) is the average of the damage time of each machine component (in this case, the charging sub-system). MTBF calculations are adjusted to the type of distribution and predetermined parameters. Table 10 shows a recapitulation of the calculation of the MTBF value of the SPKLU system.

Table 10: Recapitulation of MTBF Value Calculation of SPKLU System

Sub-System	MTBF
Charging	31,59 days
Control & Monitor	64,84 days
Communication	33,95 days

3.3.6 Component Reliability Calculation and Reliability Block Diagram

After the MTBF calculation, the reliability of each sub-system is calculated based on the statistical distribution and their respective parameters, then continued with the calculation of the overall reliability of the SPKLU system using the Reliability Block Diagram. Table 11 shows a recapitulation of the reliability value of the SPKLU system.

Table 11: Recapitulation of Reliability Value of SPKLU system

Sub-system	Distribution	MTBF		Reliability
Charging	Normal	758,286 hour	31,59 days	50 %
Control & Monitor	Eksponential	1557,632 hour	66,84 days	36,78%
Comm.	Lognormal	958,874 hour	33,95 days	67,36 %

After calculating the reliability of each location, then calculate the overall reliability using the Reliability Block Diagram (based on the SPKLU unit block diagram). Figure 1 shows the block diagram of the SPKLU unit along with its reliability value:

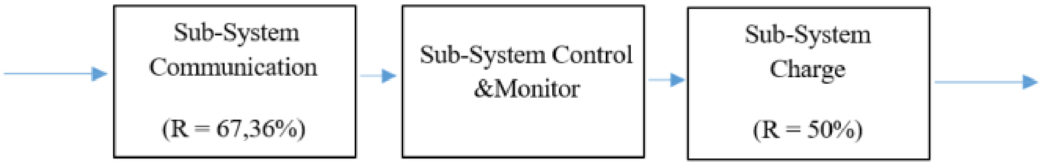

Figure 1: Reliability System SPKLU

In the picture above, the circuit of each sub-system in the SPKLU unit is in series. Therefore, the Reliability Block Diagram calculation is carried out by multiplying the entire Reliability value of each sub-system. Here is an example of the calculation:

$$R(seri)= R(Communication)\times R(Control\&Monitor)\times R(Charging)$$

$$R(seri)= 67{,}36\% \times 36{,}78\% \times 50\%$$

$$R\ (seri)= 0{,}6736 \times 0{,}3678 \times 0{,}5$$

$$R(seri)=0{,}12$$

3.3.7 Determination of Maintenance Interval

Determination of the maintenance time interval aims to determine the optimal time for component maintenance [11]. Table 12 shows a recapitulation of the calculation of the maintenance interval for the SPKLU system.

Table 12: Recapitulation of SPKLU System Maintenance Interval Calculation

Sub-system	Maintenance Interval
Charging	156,084 hour
Control & Monitor	218,518 hour
Communication	181,678 hour

IV. CONCLUSION

SPKLU reliability analysis reveals that system failures are primarily driven by short circuits, overheating, extreme weather, physical impacts, and component corrosion. Risk Priority Number calculations identify the charging cable and connector, surge protection, circuit breaker, and power contactor as the most critical components. Series configuration modeling using the Reliability Block Diagram yields partial reliabilities of 50.00% for charging, 36.78% for control and monitoring, and 67.36% for communication, resulting in a critically low overall system reliability of 12%. To improve operational availability and prevent sudden breakdowns, optimal periodic maintenance intervals are recommended at 156.084 hours for the charging subsystem, 181.678 hours for communication, and 218.518 hours for control and monitoring.

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