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Reliability, Maintainability and Availability Analysis of Solar Power Plant in Pantai Baru using Voltage Measurement Data

Patricia Fitrianingtyas[1], Muhammad Khamim Asy'ari[2], Neny Elyawati[3], Ali Musyafa'[4]
[1,2,3,4]Institute Technology Sepuluh November, Engineering Physics Department, Surabaya, Indonesia

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ABSTRACT

The hybrid power plant in Pantai Baru, Yogyakarta stands as a noteworthy exemplar within the realm of existing solar power installations throughout Indonesia. Analysis of reliability, maintenance, and availability is needed to minimize problems at solar power plant's electrical energy production process, so that renewable energy security and sustainability can be maintained. This study aims to determine the reliability, maintainability, and availability of solar panels with a capacity of 48 Volts at the hybrid power plant, Pantai Baru using the control chart method, Weibull distribution. Calculation of reliability, maintainability, and availability of solar panels is carried out using solar panel output voltage measurement data collected over the last 4 years. Time to failure, *TTF* and time to repair, *TTR* were obtained from out-of-scope data on the control chart and processed using software, namely Reliasoft Weibull ++ Version 6. The simulation results and calculations show that the distribution obtained from *TTF* and *TTR* is a three-parameter Weibull distribution, with a system reliability value of 0.3, maintainability value is 1 and availability value is 0.997 in day 5th. The reliability of each solar panel unit is 0.122 or 12.2%.

Corresponding Author:

Name: Patricia Fitrianingtyas
Institution: Institute Technology Sepuluh November, Engineering Physics Department, Surabaya, Indonesia
Email: 6009211016@studen.its.ac.id

1. INTRODUCTION

Indonesia is a tropical country with a potential source of solar energy reaching 4.8 kWh/m2/days [1][2][3]. This makes Indonesia very potential to develop solar power plants [1][2]. Solar power plants have the advantage of producing electricity when compared to wind power plants. This is because the availability of wind is a weak point of energy conversion [3]. Solar panel technology also exhibits low installation, operation and maintenance costs based on solar energy, which has a worldwide and endless distribution [4].

The hybrid power plant in Pantai Baru, Yogyakarta is a wind and solar power plant with a capacity of 83 kW [5]. The capacity of 83 kW consists of 34 wind turbines and 238 solar panels. The occurrence of voltage decreasing in the production process will interfere with the needs of the surrounding community for electrical energy. Analysis of reliability, maintenance, and availability is needed to minimize problems in the production process so that renewable energy security and sustainability can be maintained [6].

One easy-to-use method of analyzing reliability, maintainability, and availability is through control charts [7]. The distribution Weibull can detect deviations that occur when the electricity production process is operating. The presence of this deviation can indicate a malfunction in the system. Damage to equipment can be identified and then can be repaired by repairing the system or replacing components [8][9]. Analysis of mean time to repair (MTTR) will also be performed, MTTR is average time to carry out a maintenance for a component. This study aims to determine the reliability, maintainability, and availability of solar panels with a capacity of 48 Volts at the hybrid power plant, Pantai Baru using the Weibull distribution analysis.

2. LITERATURE REVIEW

2.1 First Literature

Other methods were used using control chart with distribution exponential, showed that the result of reliability reach point 0.55 at day 22nd, also means that the solar plant is not in good condition, the paper give recommendation that some maintenance shall be performed [17]. The recommendation maintenance was not explained.

3. METHODS

Calculation of maintainability, availability and reliability of solar panels is carried out using solar panel output voltage measurement data. Voltage data for solar panels are obtained from the Hybrid Power Plant in Pantai Baru, Yogyakarta. Voltage data is collected over the last 4 years. This study uses a solar power plant with a capacity of 48 Volts which is used for loading on stalls on the coast and also for lighting streetlamps. The solar power plant with a capacity of 48 Volts uses 48 solar panels with a capacity of 24 Volts each. Two solar panels are arranged in series and 24 series are produced which are then arranged in parallel.

The calculation is using Weibull distribution in which a continuous probability distribution shapes that have some parameters. The Weibull distribution parameters could represent quantity of Probability Density Function (PFD), Weibull distribution could be used for a wide variation of data. The Weibull distribution has three parameters namely β (shape parameter), represent the shape of data distribution, if $\beta > 0$, described that the form of PDF dan η (scale parameter), represent the variability present in the distribution, if $\eta>0$, it is called as characteristic life, and γ (location parameter) that represented the failure-free or early period of the tools is used. If the value of $\gamma = 0$, the Weibull distribution will be changed become two parameters form.

3.1 Control Chart

The voltage data from the voltage measurement results can be made into a control charts. From output voltage measurement data some steps to make control chart, first, define value of xi as the average voltage generated from the solar panels each

day. The second step is to define Centre line, CL is the average of the voltage data, lower control limits, LCL is the lower limits, and upper control limits, UCL is the upper limit of the control charts. LCL and UCL values use 1 sigma (1 standard deviation, σ). Equation of standard deviation (σ):

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(\bar{x}-x_i)^2}{n-1}} \quad (1)$$

From equation (1) got the value of σ is 1.594 Volt. To measure the CL, LCL, and UCL use equations (2)-(4). The control charts for the voltage data from solar panel system is shown in Figure 1.

$$CL=\frac{\sum_{i=1}^{N} x_i}{N} \quad (2)$$

$$LCL=CL-\sigma \quad (3)$$

$$UCL=CL+\sigma \quad (4)$$

Probability Density Function equation:

$$f(t)=\frac{\beta}{\eta}\left[\left(\frac{t}{\eta}\right)^{\beta-1}\right]\exp\left[\left(\frac{t}{\eta}\right)^{\beta}\right] \quad (5)$$

3.2 *Reliability, Maintanability and Availability*

Probability density function (PDF) is used to define the random variable's probability coming within a distinct range of values, as opposed to taking on any one value. Equation of Probability Density Function (PDF) Weibull as per equation (5). The TTF and TTR values are then processed using software, namely Reliasoft Weibull ++ Version 6.

To measure the reliability of PV system, calculation of hazard rate and repair rate are obtained, the equation of three parameters Weibull distribution hazard rate and repair rate are shown on equation (6)-(9) and the result analysis graphic show on Figure 4.

$$\lambda(t)=\frac{\beta}{\eta}\left(\frac{t-\gamma}{\eta}\right)^{\beta-1} \quad (6)$$

$$\lambda(t)=0.2783\left(\frac{t-0.7275}{3.1273}\right)^{0.8703-1} \quad (7)$$

$$R(t)=\exp\left\{-\left(\frac{t-\gamma}{\eta}\right)^{\beta}\right\} \quad (8)$$

$$r(t)=1.0953\left(\frac{t-0.9575}{0.4479}\right)^{0.4906-1} \quad (9)$$

The reliability R(t) will be calculated based on the results of the TTF distribution approach, the equation is shown in equation (10)-(11) and the reliability graph is shown in Figure 5. The maintainability equation, M(t) based on the results of the TTR distribution approach is shown in equation (12) and the maintainability graph is shown in Figure 6. The availability equation, A(t) is shown in equation (13) where λ is failure rate from the time between the failure, and μ is 1/MTTR and the availability graph is shown in Figure 7.

$$R(t)=\exp\left\{-\left(\frac{t-\gamma}{\eta}\right)^{\beta}\right\} \quad (10)$$

$$R(t)=\exp^{-\left(\frac{t-0.7275}{3.1273}\right)^{0.8703}} \quad (11)$$

$$M(t)=1-\exp^{-\left(\frac{t-\gamma}{\eta}\right)^{\beta}} \quad (12)$$

$$M(t)=1-\exp^{-\left(\frac{t-0.9575}{0.4479}\right)^{0.4906}} \quad (13)$$

$$A(t)=\frac{\mu}{\lambda+\mu}+\frac{\lambda}{\lambda+\mu}\exp\left(-(\lambda+\mu)t\right) \quad (14)$$

3.3 *Reliability of Solar Panel Array*

There are two types of solar panel array, they are series and parallels. Series solar panel array, all the components must function normally. If E1 = non failure event component 1, E2 = non failure event component 2. If, P(E1) = R1 and P (E2) = R2, where R1 is the reliability of component 1, R2 is the reliability of component 2. The series array of solar panels is shown on Fig. 1.

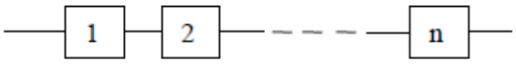

Fig. 1. Series Solar Panel Array (Ebeling, 1997)

Reliability formulation for series solar panel array configuration is shown on equation (15) (Ebeling, 1997).

$$RS = P(E1 \cap E2) = P(E1)P(E2) = R1(R2) \quad (15)$$

Parallel solar panel array if all components fail then the system will not run. However, if one component fails and the other components are still performing their functions well, then the system can still run. The parallel array of solar panels is shown on Fig. 2.

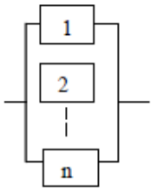

Fig. 2 Parallel Solar Panel Array

Reliability formulation for series solar panel array configuration is shown on equation (16) (Ebeling, 1997)

$$RP = P(E1 \cup E2) = 1 - P(E1 \cup E2)C = 1 - P(E1C)P(E2C) = 1 - (1 - R1)(1 - R2) \quad (16)$$

Reliability parallel solar panel array formulation for general as shown on equation (17) (Ebeling, 1997).

$$RP(t) = 1 - \prod_{i=1}^{n} = [1 - R1(t)] \quad (17)$$

4. RESULTS AND DISCUSSION

4.1 Control Charts

From the graphic that is shown on Figure 3 below, CL value is 54.659 Volt, the LCL is 53.065 Volt and the UCL is 56.254 Volt. The value of the voltage that comes out of the LCL and UCL is considered a failure, so that the time to failure, TTF and time to repair, TTR values can be determined.

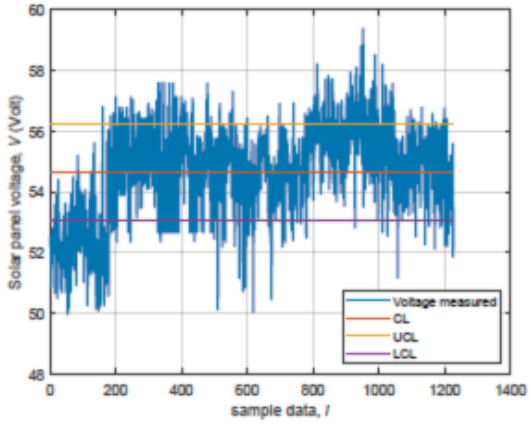

Figure 3 Control chart for solar panel voltage.

4.2 Reliability, Maintanability and Availability

The graph of probability density function for TTF and TTR which is the result of data processing through Reliasoft Weibull ++ Version 6 is shown in Figure 4 and Figure 5. Figure 4 can be seen that the distribution obtained from TTF is a three-parameter Weibull distribution with β is 0.8703, η is 3.1273, and γ is 0.7275. The three-parameter Weibull distribution for TTR are shown on Figure 5 with β is 0.4906, η is 0.4479, γ is 0.9575.

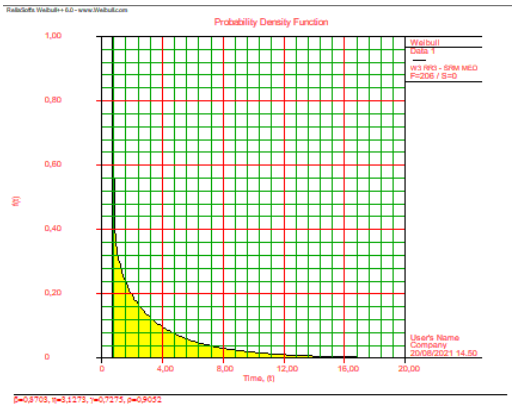

Figure 4 Probability Density Function of TTF.

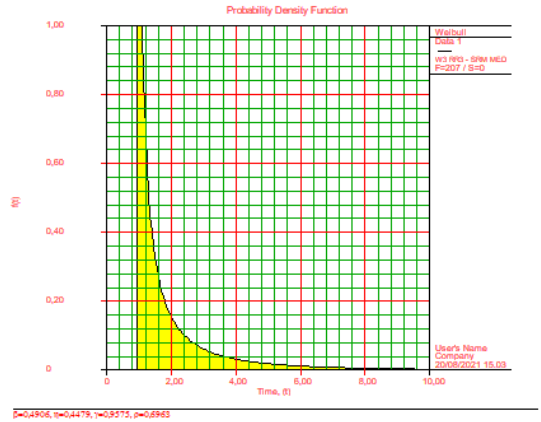

Figure 5 Probability Density Function of TTR.

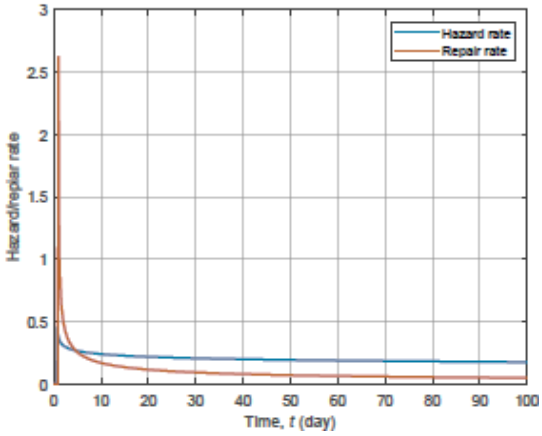

Figure 6. Graph of hazard rate and repair rate.

Figure 6 is the graph of the hazard rate and repair rate decreases with uptime. The failure rate is included in the decreasing failure rate (DFR). The occurrence of failures is related to quality and results from defects due to imperfect design, assembly, initial production and can also be caused by human error during installation and operation.

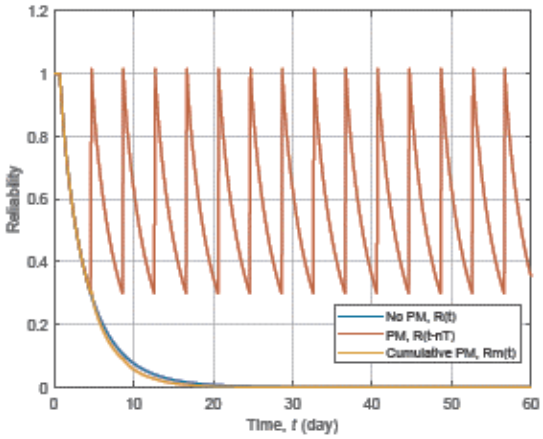

Figure 7 Graph of reliability.

Figure 7 shows that the reliability value decreases with time. The reliability value of 0.3 occurs at operational time for 5 days. This shows that the life cycle of the system can carry out its functions with a 30% chance of success every 5 days. The reliability value of 0.3 was obtained for the solar panel system based on previous research [10]. The reliability value of the system after preventive maintenance is lower than before treatment. This is because the failure rate is included in the decreasing failure rate so that the treatment measures applied are not effective, causing the reliability value to decrease with time.

From Figure 8, can be seen that the maintainability reaches a value of 1 in an interval of less than 1 day which indicates that the 100% system maintainability is achieved in less than 1 day.

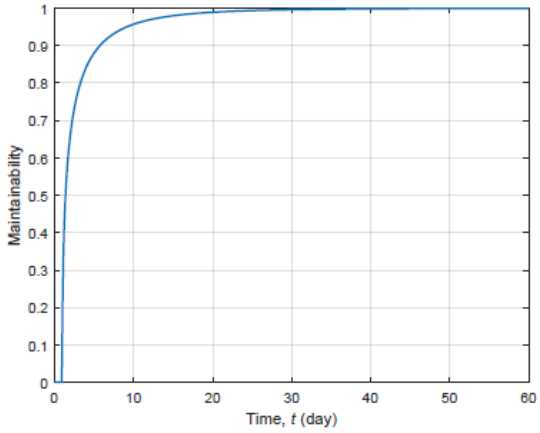

Figure 8 Graph of maintainability.

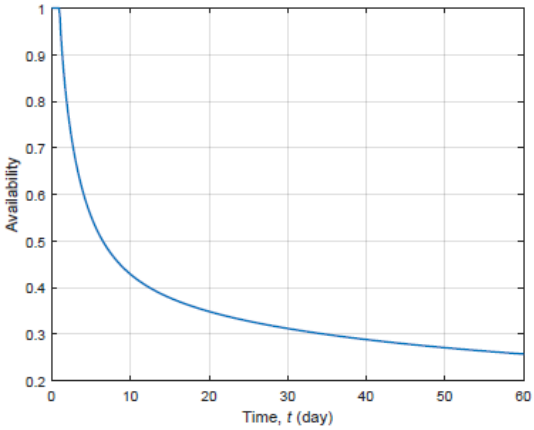

Figure 9 Graph of availability.

Figure 9 shows that the availability value decreases to 0.3 at 35 days uptime. System availability for 5 days uptime is 0.56. Availability is determined by reliability and maintainability. Reliability and maintainability have independent factors that do not affect each other. Reliability is determined by the frequency of system or component failures. Reliability will be lower if the system or component is damaged more often and vice versa. Maintainability is determined by the ability to repair damaged systems or components. Maintainability will be higher if the ability to repair damage is higher and vice versa.

4.3 Reliability of Sollar Array

The solar power plant system consists of two units of solar panels arranged in series so that there are 24 solar panel subsystems. 24 solar panel subsystems are paralleled to produce 10.5 kW of electrical power. The scheme of the solar panels array in a solar power plant system with a capacity of 48 Volts is shown in Figure 10 below.

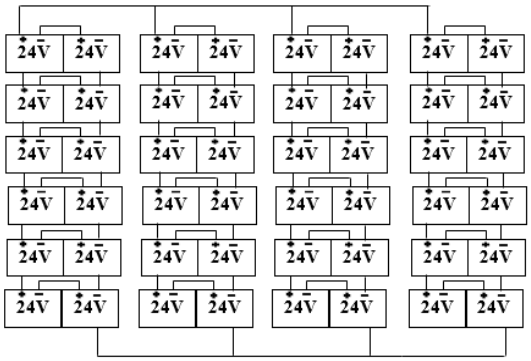

Figure 10. The scheme of the solar panels array

The solar panel as a whole system, based on Figure 8, has a reliability of 0.3. The calculation of the reliability value of each solar panel can be determined by assuming that each solar panel is identical and calculated using equation (17).

$$R_{system}(t)=1-(1-(R_{PV}(t))^2)^{24} \quad (17)$$

The calculation results from equation (15) show that the reliability of each solar panel unit is 0.122 or 12.2%. The results of the overall reliability calculation and each solar panel unit show that the solar panel series array will decrease reliability, while the solar panel parallel array will increase reliability. The solar panels parallel array is used to increase the electric current but the production of electric voltage generated by the solar panels will remain. The failure of one or several solar panels will not affect the overall system performance if the solar panels are arranged in parallel, so that the parallel array of solar panels is used as an effort to increase the reliability of the system.

The author compiles, analyzes, evaluates, interprets and compares the results of the latest findings with existing research findings. The author must pay attention to the consistency of the article from the title to the bibliography (10 pt).

Existing tables or figures are presented with sufficient explanations and by including numbers and titles. Complete the existing tables and figures by writing the source under each table/figure. The table is created without a vertical border. Example table.

5. CONCLUSION

Analysis of reliability, maintainability, and availability of a solar power plant is important and needs to be done to maintain renewable energy security and sustainability. Calculation of reliability, maintainability, and availability of solar panels can be determined using Weibull distribution and Reliasoft Weibull software. The calculation result showed the system reliability value is 0.3 and reach value 0.56 in 5 days, the maintainability value is 1 and the availability value is 0.997. From the result can be seen that the quality of system photovoltaic is poor. Despite the result from graphic analytical, reliability of solar panel array was calculated, the result showed that reliability values are obtained after the solar panel operational time period of 5 days. The reliability of each solar panel unit is 0.122 or 12.2% which means that solar panel array also affects the reliability value of PV system. Preventive maintenance needs to be carried out to prevent damage or decrease in the voltage generated by the PV system. Some step of preventive maintenance should be done such as check the position of the solar panel if there any shadow on it and the condition of solar panel mainly the condition off the cells, condition of battery inverter, battery condition, distribution panel condition and grounding system.

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BIOGRAPHIES OF AUTHORS

Patricia Fitrianingtyas I was graduated from Universitas Kanjuruhan Malang at 2017, majoring Physics. Now, I am a postgraduate student at Institute Technology Sepuluh November, majoring Physics Engineering. My area expertise is in instrument engineering mainly at field instrument, and I am interested in studying more about the renewable energy and it system. My interest at research is about reliability, availability, and maintainability of a solar system, I,m doing the research on a solar power plant in Indonesia.
Email : 6009211016@student.its.ac.id

M. Khamim Asy'ari A young lecturer of Institute Technology Sepuluh November, with interested in Reliability Engineering and Safety. Graduated from doctoral degree in 2023 at Institute Technology Sepuluh November.