

Reliability, maintainability and availability analysis of solar power plant in Pantai Baru using voltage measurement data

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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 with a solar panel operating time period of 5 days. The reliability of each solar panel unit is 0.122 or 12.2%.

1 Introduction

Indonesia is a tropical country with a potential source of solar energy reaching 4.8 kWh/m²/days [1]. This makes Indonesia very potential to develop solar power plants [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 problems 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 [4].

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One easy-to-use method of analysing reliability, maintainability, and availability is through control charts [6]. 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 [7,8] Analysis of mean time to repair (MTTR) also will 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 Method

Calculation of reliability, maintainability, and availability 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 street lamps. 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 (PDF), 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 Result analysis

3.1 Analysis of reliability, maintainability and availability

3.1.1 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 x_i as the average voltage generated from the solar panels each day. 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 used equation (2)-(4). The control charts for the voltage data from solar panel system is shown in **Fig. 1**.

$$CL = \frac{\sum_{i=1}^N x_i}{N} \tag{2}$$

$$LCL = CL - \sigma \tag{3}$$

$$UCL = CL + \sigma \tag{4}$$

3.1.2 Reliability, maintainability and availability

From the graphic that is shown on **Fig. 1** 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.

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.

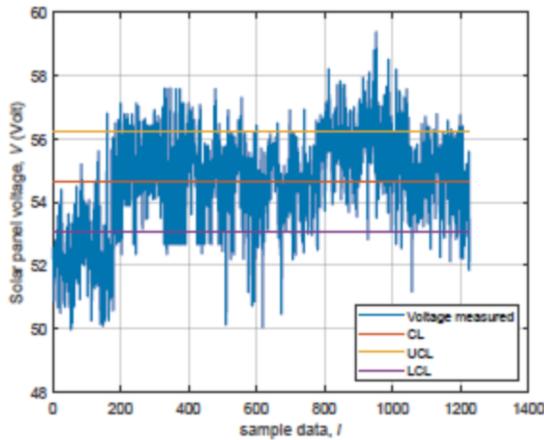


Fig. 1. Control chart for solar panel voltage.

Probability Density Function equation:

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

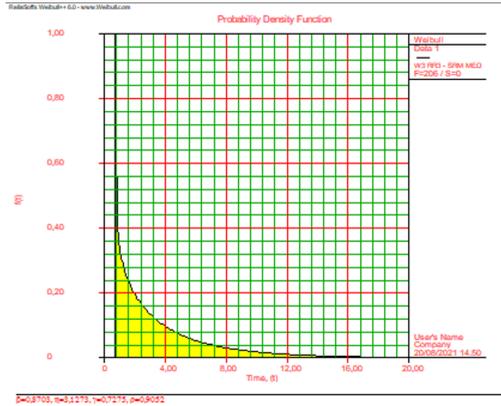


Fig. 2. Probability density function of TTF.

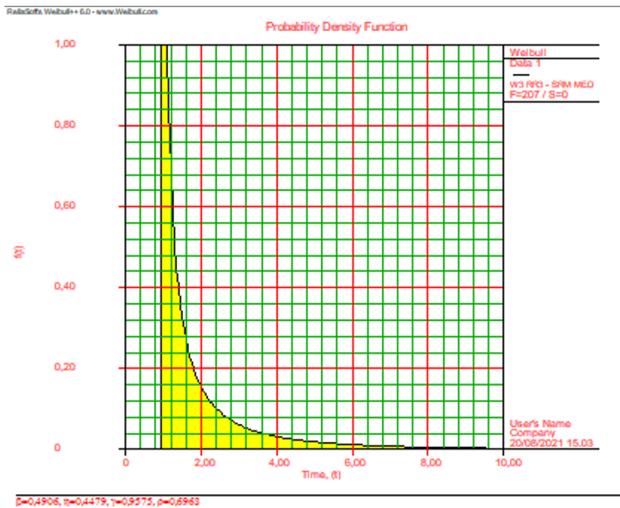


Fig. 3. Probability density function of TTR.

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 Fig 2 and Fig 3. **Fig. 2** 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 **Fig. 3** with β is 0.4906, η is 0.4479, γ is 0.9575.

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 **Fig. 4**.

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

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

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

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

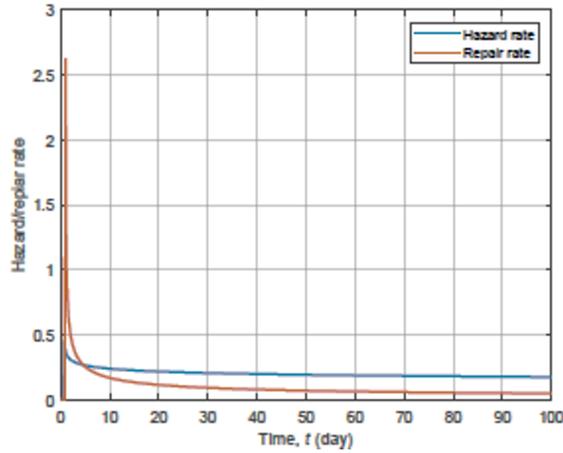


Fig. 4. Graph of hazard rate and repair rate.

Fig. 4 shows that 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.

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 **Fig. 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 **Fig. 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 $1/\text{MTTR}$ and the availability graph is shown in **Fig. 7**.

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

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

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

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

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

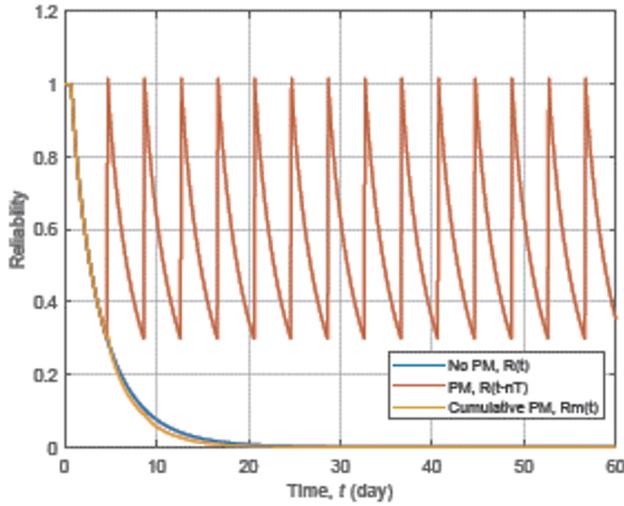


Fig. 5. Graph of reliability.

Fig. 5 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 [9]. 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.

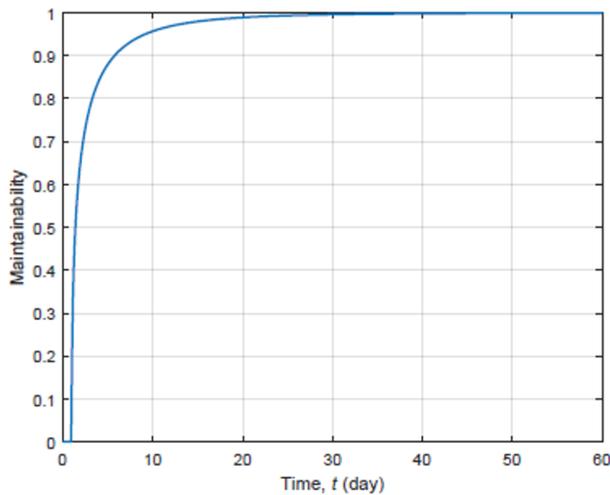


Fig. 6. Graph of maintainability.

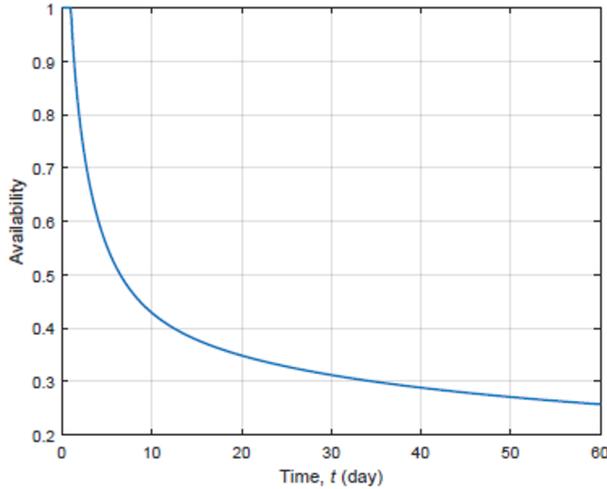


Fig. 7. Graph of availability.

Fig. 6 shows 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. **Fig. 7** 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. Each reliability and maintainability has 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. Other methods were used using control chart with distribution exponential [7], showed that the result of reliability reach point 0.55 at day 22nd, also means that the solar plant is not in good condition, some maintenance shall be performed.

3.2 Reliability in solar panel 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 **Fig. 8** below.

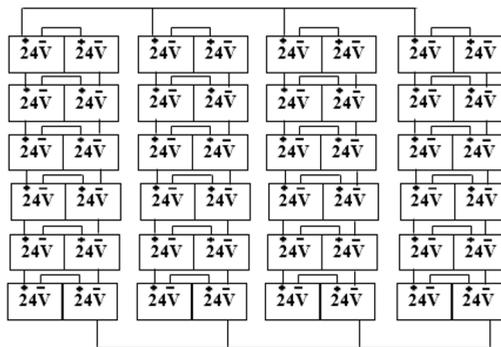


Fig. 8. The scheme of the solar panels array.

The solar panel as a whole system, based on **Fig. 6** 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 (15).

$$R_{system}(t) = 1 - (1 - (R_{PV}(t))^2)^{24} \quad (15)$$

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.

3.3 Maintenance recommendations on Photovoltaic system

Fig. 5 shows that 48 V PV systems have poor reliability values, maintenance recommendations need to be given. Maintenance on Photovoltaic (PV) is intended for reliable and continuous system continuity [9]. Maintenance needs to be done correctly and regularly. Maintenance recommendations on whole parts of PV system are as below:

3.3.1 Solar module

There are some conditions of solar modules to be checked regularly [9], they are: Cleanliness, to check if there is dust, foliage, garbage, or dirt covering the surface of the solar module and the dirt should be cleaned regularly. Shadow, to check if the surface of solar module covered by shadow from trees or other buildings as shown on **Fig 9.**, in that condition, the tree needs to be cut. Environment, to clean up the environment around the solar module. Overall condition, to check the condition of solar modules if there are some breaks, broken laminate, cell color and hotspot on solar module, the cables, and check all bolts (tightness and if any missing bolt).



Fig. 9. Shadow on solar modules.

3.3.2 Solar charge controller or battery inverter

The condition of solar charge controller or battery inverter shall be checked and maintain regularly [9]. The part that should be checked are inverter ventilation cleanliness if there are some dirt on inverter ventilation, charge controller, tray of cable power and cable data shown on **Fig. 10**. Other parts that should be checked are voltage recording, indicator on battery inverter, to ensure the battery inverter working normally and check the cables condition to reduce voltage loss.



Fig. 10. Cable tray condition.

3.3.3 Battery

Battery condition that shall be checked regularly are the cleanliness, the condition of battery room shall be clean, the proper condition of battery room is shown on **Fig. 11**. Battery temperature condition, the battery temperature shall be less than 300 °C. Physical battery check if any physical changes in battery such as bulging, cracking, etc. Battery leakage, to check if any electrolyte leakage on each battery, also to check regularly the condition of terminal cable, if any rusty cable or any oxidation on the cable terminal.

3.3.4 Combiner box

The combiner box shall be checked regularly, some conditions that shall be checked are the condition of MCB, fuse, surge voltage protection are in a good condition. The cable connection is safe, dry, and clean. To check inside the combiner box there are no holes, water or animal nest as.



Fig. 11. Battery

3.3.5 AC/DC distribution panel

AC/DC Distribution Panel shall be checked regularly, the panel shall be free of dirt and bugs, to record the output energy of AC Distribution Panel and calculate the difference of energy output each day and one day before. Check the MCN, fuse, surge voltage protection and energy meter on panel are in good condition. All components shall be made sure not burned or peeled off.

3.3.6 Grounding system

To check the grounding systems are installed properly, if there is any unused or peeled grounding cable, it shall be electrically insulated.

4 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 of 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 mean that solar panel array also affects the reliability value of PV system. Preventive maintenance needs to be carried out to prevent damage or decreasing in the voltage generated by 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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