The reliability study of Gili Trawangan photovoltaic system using RBD (Reliability Block Diagram) method

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Abstract. In order for Gili Trawangan On-grid photovoltaic (PV) system to be reliable in supplying electricity, it is necessary to know the reliability of the main equipment in the PV system. The aim of this study is to determine the reliability of the main equipment of the on-grid PV system. The methodology is, collecting primary data in the form of disturbance data reports on Gili Trawangan PV system in 2011-2018, compiling the Reliability Block Diagram (RBD) of the PV system and determining the reliability and critical of the PV system equipment using Reliasoft Blocksim software version 11. The On-grid PV systems Reliability Block Diagram consists of 3 sub-systems; Source system, String Combiner System and Power Conditioning System, each of which is composed of main components. RBD simulation results with Reliasoft Blocksim software obtained the results that the reliability of the On-grid PV system is 49% at t=100 hours and 40% at t=300 hours, this condition is still far from the target of PV system reliability of 80%. From the simulation also obtained critical equipment on the On-grid PV system is an AC Inverter and Breaker component, which has a high Reliability Importance (RI) value and with the highest reliability value.

1. Introduction

In recent years, with ongoing fossil energy depletions, solar photovoltaic (PV) power has become one type of potential renewable power generation technology that developed rapidly in a tropical country like Indonesia. PV system as a renewable power plant, has a significant role in electrifying remote islands in Indonesia. PV system connected to the grid is one solution to reduce the cost of procurement of PV system given the expensive battery price [1]. Therefore, in its application in the field, On-grid PV system configuration commonly used by PLN. With the large PV system capacity, the reliability of the electric power system in Indonesia will be influenced by the reliability of the PV system. In order for the PV system to be reliable in supplying electricity to remote islands in Indonesia, it is important to know the reliability of the main equipment in the PV system. The reliability analysis also makes it possible to establish an acceptable maintenance plan for both the user and the system as efficiently as possible [2].

To find out the reliability of the main equipment in the PV system, it is necessary to carry out a case study on the reliability of the On-grid PV system. However, in the design of PV system a reliability analysis is often missing in the feasibility study or is simply required due to an incomplete methodological approach or lack of specific simulation tools [3]. A few studies have evaluated the reliability and availability of PV systems and their components using general reliability analysis methods, such as fault tree, Monte Carlo simulation, Petri nets, and Markov model [4,5]. Several studies have been carried out to evaluate the reliability of PV system using Reliability Block Diagram (RBD)
method [6-8]. In Jain et al presents a reliability evaluation method of an electric power generation system including PV sub-system, but reliability is considered here as the capability of the PV system to provide power to the load depending on the variability of meteorology conditions, given all system components never fail [7].

In this paper, the development of Reliability Block Diagram (RBD) method using ReliaSoft BlockSim version 11™ to determine the reliability of the PV system. RBD have been developed for: (1) definition of PV systems, (2) description of interdependence between components, (3) identification of how the degrade/failure, and (4) appreciation of how the PV system reliability is influenced.

After determining the reliability of the system, the next thing to do is identify the components that cause the most problems in the system to prioritize improvements in design and resources and efforts to improve the system in the direction that has the greatest impact on system performance. Reliability Importance (RI) is one of the steps taken to identify weaknesses in the system.

2. Method

In order to perform a fairly accurate reliability analysis of the PV systems and their components, the authors have chosen to use the BlockSim simulation platform. A hierarchical system model was developed describing the functional elements necessary to deliver power to the grid using a commercial software tool, ReliaSoft BlockSim 11™.

In this paper, the Gili Trawangan PV system unit 1 capacity 200 kWp was evaluated, the solar module used was 29.5 V DC, 220 Watt peak. Each string consists of 20 solar modules connected in series. The PV system has 4 parallel connected arrays, where array 1 and array 2 have 12 strings each, while array 3 and array 4 have 11 parallel connected strings each.

![Figure 1. Gili Trawangan on-grid PV unit 1 system topology configuration.](image)

From figure 1 above, it shown that from the array of solar module outputs, it is forwarded to a grid tie inverter with a capacity of 250 kW with a breaker in the combiner box. Furthermore, direct current power is converted to alternating current power by a grid-tie inverter. The output from the inverter is then passed on the distribution panel to be divided into internal usage (local load) or outside network. PV system uses a central Inverter configuration with an input voltage value in the medium voltage category (> 500V), which is Vmpp = 590 V per string. This configuration provides the advantage of a low DC loss value.

Before modeling the RBD, first determine the system, sub-system, and relationships between systems and sub-systems. The system then breakdown to level sub-system to the component level. Determination and identification of this system based on functional relationship on systems, the components that exist in the system. This thing is done to find out which interactions occur between sub-systems then interactions between components, especially if the components has a different reliability value. To find
out the relationship between systems can be done by looking at single line diagram of the PV system. On the on-grid PV system there are the source system sub-system, the string combiner sub-system and the power conditioning sub-system. For more details, see in figure 2.

![Figure 2. On-grid PV sub-system grouping diagram [5].](image)

2.1. Determine the distribution and data distribution parameters between failure

After the historical data has been tested for IID (Identical Independent Distribution), the next step is to determine the parameters and distribution patterns of the data. In this study the data is assumed to have been an IID this is due to data limitations so it is feared that the data obtained is not enough to carry out further data processing. To determine the distribution patterns and distribution parameters using Weibull ++ software. The first step is to write down the failure data for each component on the "Time failed (hr)" sheet. This data shows the Time between Failure (TBF) the component. After that, select "Distribution Wizard" to determine the priority of the distribution. After calculating using Weibull ++ software for all sub-system components in the Gili Trawangan PV system unit 1, it is known that the available data is insufficient to meet the needs of failure data and repair data on the on-grid PV system. Primary data is insufficient for further calculations using RBD simulations. Another way to fill in the blank data is with secondary data. Data on the distribution of failure and repair of PV Gili Trawangan that have been equipped with secondary data, see table 1 and table 2:

| Component       | Distribution | Failure Parameter | |
|-----------------|--------------|-------------------|---|
| PV Module       | 3P Weibull-RRX | Eta (η) or Log Mean | Beta (β) or Log SD | Gamma (γ) |
| Junction Box    | 2P Weibull-RRX | 5.2E+12            | 0.28                 | 17       |
| Combiner Box    | Lognormal 2-RRX | 1.2E+06            | 0.51                 |          |
| Inverter        | 2P Weibull-RRX | 10                 | 2.3                  |          |
| Fuse AC         | 2P Weibull    | 40655.35 hours     | 111.0869 hours       |          |
| Breaker AC      | 3P Weibull-RRX | 714.27             | 13.03                |          |
| MV Transformer  | 3P Weibull-RRX | 11,000             | 0.35                 | 3.9      |
|                 |               | 1.3E+10            | 0.15                 | 28       |
Table 2. Distribution and parameters of repair distribution of Gili Trawangan PV system [8,9].

| Component        | Distribution     | Eta (η) or Log Mean | Beta (β) or Log SD | Gamma (γ) |
|------------------|------------------|---------------------|--------------------|-----------|
| PV Module        | Lognormal 2-RRX  | -1.37               | 3.11               | 17        |
| Junction Box     | Lognormal 2-RRX  | -0.98               | 2.07               |           |
| Combiner Box     | Lognormal 2-RRX  | 3.55                | 0.35               |           |
| Inverter         | Lognormal 2-RRX  | 1.5026              | 2.27               |           |
| Fuse AC          | Lognormal 2      | 0.54308             | 0.65067            |           |
| Breaker AC       | 2P Weibull-RRX   | 1.4                 | 0.7                | 3.9       |
| MV Transformer   | Lognormal 2-RRX  | -2.33               | 1.6                | 28        |

In this study secondary data from journals was used [8,9]. This is because the limitations of the data obtained from PV system are not sufficient to do calculations in determining the distribution and distribution parameters. Secondary data obtained from journals and previous studies that have the same scope, namely solar power plants connected to the network with the same assumed conditions. The limitations of the data will have an impact on the results of the study for some components in the Reliability Block Diagram does not have a failure distribution and repair distribution so that the RBD model that is built does not model the condition of the real system.

2.2. Forming a reliability block diagram

The components that are already known for their distribution patterns and distribution parameters are then formed by the RBD in accordance with the description of the system running on the actual system.

Figure 3. RBD model for (a) source system, (b) string combiner system, (c) power conditioning system.

The model created is a model that illustrates the relationship between one components with another component. Therefore, this research involves many operators in building the Reliability Block Diagram model. The involvement of the operator unit begins with the making of the RBD which is the translation
of the single line diagram owned by the operator so that the operator has a very important role in providing information about the components, the relationships between the components contained in the company. In addition, the operator also plays a role in making simulation models. Here the operator has a role in providing the system logic contained in real conditions. This is because the operator knows more about the condition of the system working normally. The logic provided is then built into a simulation model.

The description of the RBD of Gili Trawangan PV system unit 1 200kWp for the source system see figure 3(a), for the string combiner see figure 3(b), and for the power conditioning system see figure 3(c). RBD is not a work process configuration but a picture of the configuration of relationships between systems, sub-systems and components in the system. Therefore, the RBD above is not a description of the work process of the system.

Figure 3(a) is a description of RBD for the source system. In the single line diagram, it is known that the relationship between the solar module string systems in the source system is parallel, so that if one string fails it does not affect the other components and is an RBD overview for the string combiner system. Figure 3(b) is an RBD overview for the string combiner system. In the single line diagram, it is known that the output of each solar module array is connected in series to the combiner box. There are 4 combiner boxes arranged in parallel. Figure 3(c) is a description of the power conditioning system RBD where all the components are arranged in series. The power conditioning sub system has 6 main components that are taken into account in the RBD simulation, namely: dc fuse, dc switch, inverter, ac breaker, ac fuse, and 380V / 20kV distribution transformer. In the RBD simulation of the on-grid PV system the dc fuse and dc switch components are assumed to have a constant reliability value of 80%.

3. Results and discussion
The simulation results for RBD design in each system are obtained. The RBD simulation results on Gili Trawangan PV system are obtained by running the simulation with Reliasoft Blocksim Software with 10,000 hours end time simulation with t = 100 hours and t = 300 hours see table 3.

Table 3. Gili Trawangan PV system unit 1 RBD simulation results (t = 100 hours and t = 300 hours).

| System overview                          | Time simulation       |
|-----------------------------------------|-----------------------|
|                                         | t = 100 hours | t = 300 hours |
| Mean Availability (All Events):         | 0.527843     | 0.432389     |
| Standard Deviation (Mean Availability): | 0.49969      | 0.494998     |
| Mean Availability (w/o PM, OC & Inspection): | 0.527843 | 0.432389 |
| Point Availability (All Events):        | 0.49         | 0.42         |
| Reliability:                            | 0.49         | 0.4          |
| Uptime (hr):                            | 52.78427     | 129.7167     |
| Total Downtime (hr):                    | 47.21573     | 170.2833     |

From table 3 above, it is shown the reliability of the system for 100 hours is 0.49 or 49% with an average uptime is 52.78 hours and a total downtime of 47.21 hours. The reliability of the system for 300 hours is 0.4 or 40% with an average uptime of 129.7 hours and total downtime of 170.3 hours. The system reliability obtained is quite far with the reliability target that the unit wants to achieve that is 80%. The value of reliability t = 100 hours and t = 300 hours has decreased from 0.49 or 49% to 0.4 or 40%. The on-grid PV system failure is defined as derating and/or outage. So the reliability of R (100) Gili Trawangan PV system = 49% and R (300) = 40% can be represented as the probability of Gili Trawangan PV system not to experience derating or outage for 100 hours is 49% and for 300 hours is 40%.
Figure 4. Static Reliability Importance (RI) Gili Trawangan PV system.

From figure 4 above, it is known that the inverter and ac breaker components have high Reliability Importance (RI) values and the highest reliability values. Both of these components have the greatest influence on the On-grid PV system in achieving system reliability values. The Inverter and ac breaker are the critical components of power conditioning system. The inverter has the highest damage frequency compared to other components and generally causes no-output condition for PV system. The causes of the inverter damage include: controlling software, the influence of bad weather, insulation damage, lighting, overvoltage, and others [10].

Unfortunately, the reliability value on the Gili Trawangan PV system is not able to describe the condition of the real system due to data limitations so that there are components in each sub-system that do not have the value of the distribution of damage and/or distribution of repairs. This affects the value of system reliability where the value of system reliability is composed of the reliability value of each component. If one component in the system does not have a damage distribution, the resulting reliability comes from components that have a damage distribution value, other than that the component is considered never to fail. Therefore, the results of system reliability on the on-grid PV system cannot yet represent the real system.

To improve the reliability of the On-grid PV system and its components, it is necessary to develop a detailed failure management strategy. More data is needed to obtain reliability calculation that better reflect real system condition, so it would be better if the PV system company equipped with Computerized Maintenance Management System (CMMS) as an essential tool for recording interruption database in real time. Further research that can be done is a comprehensive evaluation of the reliability of PV system using solar availability data throughout the year at the location of the PV system.

4. Conclusion
In this study, the reliability of Gili Trawangan PV system has been simulated with Reliasoft Blocksim software and the numerical values has been computed from the system considered. Unfortunately, there is no data that meets the need to do RBD on-grid PV simulations. Therefore, for the simulation of RBD the On-grid PV system is entirely equipped with secondary data.

It is found that the reliability of the On-grid PV system is 49% at t=100 hours and 40% at t=300 hours, this condition is still far from the target of PV system reliability of 80%. From the simulation, it
has been obtained that critical components On-grid PV system are AC Inverter and Breaker component, which has a high Reliability Importance (RI) value and with the highest reliability value. These studies are intended to give a better insight to PV system designer and its operator to evaluate the reliability of on-grid PV system. More data is needed so that reliability calculations can better reflect real system conditions.

Evaluation of PV system reliability in this article is the initial stage of a comprehensive evaluation of PV system reliability. A comprehensive evaluation will involve data on the availability of sunlight throughout the year at the site where the PV system was built. This study will be a continuation of this research.

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