Evaluation of power plant reliability using index loss of load in the Suralaya power plant

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Abstract. Suralaya Power Plant (SPP) is the largest capable electricity generation company in Indonesia, with a total installed capacity of 3400 MW. As the largest power plant in Indonesia, SPP holds a great responsibility as a supplier of 17% of the electricity needs of the Java, Madura and Bali (JAMALI) systems. This makes the SPP also one of the national vital objects (Obvitnas). This paper will calculate the reliability index of the generator using the method of loss of load probability (LOLP) and loss of load expectation (LOLE) based on the value of the force outage rate (FOR). Based on data on failure and daily expenses in 2019, the reliability index of SPP for units 1-4 is 4.23 days per year or 1.23%. The higher values LOLP/LOLE are in 2019 are the possibility of SPP has lost its burden for 2 days in a period of 2019 because of force majeure (blackout) which causes a reduced load. To improve power plant is that the electricity load in West Java can be fulfilled with the electricity flow.

1. Introduction

The power generation unit has a role as a generator of electricity for both household and industrial use. If a generating unit is damaged or in worst condition blackout happen, it can result in the unit not operating. If several large generating units experience this simultaneously, a load release or system loss can occur. If a generation unit often experiences load shedding, then the generation unit is not reliable in serving loads. Given the important role of generating units in the availability of electric power available, it is necessary to maintain the reliability of these generating units.

Reliability is the opportunity of an equipment to operate as planned well in a certain time interval and certain operating condition. The reliability of the electric power system is a measure of the level of service to the fulfillment of consumer electrical energy needs. There are four factors related to reliability, namely probability, working according to function, time period, and operating conditions [1,2].

The electricity generation system contained in the Suralaya power plant is a continuous process, which when a failure occurs in an engine component can result in the cessation of the machine so that the system's function is disrupted. Based on kerusakan data, it is known that during 2019 there were several engine failures which even caused the unit to stop operating. One of them is the leakage of boiler unit 3 in August. As the largest electric power generation service unit plus 50% of electricity demand produced at the Suralaya power plant and cover 17% of the electricity needs of the JAMALI system (Java Madura Bali). The Suralaya power plant should keep the generating unit in a reliable condition so that it can serve the needs of the power load required.

Based on the above problems, the company needs to know the probability that the operating units of the plant cannot serve the load. So that in the future the company can predict the needs of power reserves needed by consumers and can minimize the occurrence of things that are not desirable.
2. Methodology
In this paper to know the probability loss of load is using analytical technique from measures or indicators to find mathematical solutions. The system can be found resulted measures or indicators which appropriate to the evaluation technique based on assumptions and input data used in the models [6].

The probability of aggregate loss of capacity is calculated from basic probability principles and combining power of different generating unit from 1-4. The result can be presented in table of capacity outage probability. Another data needed is availability and unavailability of each generating unit.

The basic probability principles and combining the different generating units are used for calculating the probability of aggregate loss of capacity. The data and the results are usually represented in capacity outage probability tables. The success probability or availability and its complement, i.e., failure probability or unavailability of each generating unit are the input data.

In this paper is used the steps from define until suggestion. The flow chart research is presented in figure 1.

![Flow Chart](image)

**Figure 1.** Flow chart

2.1. Availability and outage measures
In a Markov process, a component system especially in repairable electric power can be presented in two condition based on their life history there are functioning conditions (up) denoted by 1 and unavailable conditions (down) denoted by 0.[7]

For condition component fails, there is a transition from up state to down state. When a component repairs, there is a transition from down state to up state.

Thus when the component fails, it is said to undergo a transition from the as much as the down state, and conversely, whilst repairs are over, it is stated to return from the right down to the up state. This idea then allows to interpreting the idea of reliability in phrases of the fraction of overall time the aspect remains inside the up state. The duration of functioning length is also called the time-to-failure, and that of the duration under restore because the downtime.
The probabilistic technique to power system reliability analysis views the machine as a stochastic manner evolving over time. At any second the machine may alternate from one nation to another due to activities such as element outages or deliberate maintenance. Corresponding to a couple of states, say (i, j), there’s a conditional opportunity of transition from the state i to the state j. All combinations of to be had and unavailable generating units are offered in tabular shape together with the calculated machine availability.

2.2. Inherent availability
The inherent availability, $A_{inh}$, is defined:

$$A_{inh} = \lim_{T \to \infty} A(T) = \frac{MTBF}{MTBF + MTTR}$$ (1)

The inherent availability is based totally at the failure distribution and repair-time distributions. It can therefore be viewed as an equipment design parameter, and reliability-maintainability trade-offs can be based totally on this interpretation [8].

2.3. Loss of load probability
A loss of load likelihood (LOLP) could be a probabilistic approach for determination of needed reserve. This approach examines the possibilities of synchronous outages of generating units that, along sides a model of daily peak-hour hundreds, confirm the quantity of days annually of expected capability shortages. [1]. Today, LOLP is that the most generally accepted approach within the utility business for evaluating generation capability needs. [2]

Loss of load happens whenever the system load exceeds the accessible generating capability. The LOLP is defined because the chances of the system load accessible generating capability underneath the belief that the height load is taken into account as constant through the day. The loss of load chance doesn’t very signify a probability. It expresses statistically calculated price representing the share of hours or days in a very bound time-frame, once energy consumption cannot be coated considering the chance of losses of generating units. This point frame is typically one year, which might be painted as 100 percent of your time frame. In different words, the LOLP stands for associate expected proportion of hours or days p.a. of capability shortage. The LOLP truly doesn’t signify a loss of load however rather for a deficiency of put in accessible capability.

The term LOLP is closely involving the term loss of load expectation (LOLE). If the interval used for the LOLP is expressed within the time units instead in proportion values, the LOLE is obtained rather than the LOLP. The generation system planners will appraise generation system dependableness and verify what proportion capability is needed to get a specified level of LOLP. As demand grows over time, extra generating units are enclosed during a means that the LOLP doesn’t exceed the desired criterion. LOLP typically varies exponentially with load changes. Whereas the impact of random outages is evaluated probabilistically, regular outages are evaluated deterministically. Risk criteria comparable to proportion reserve and loss of target unit don’t define systematically truth risk within the system.

2.4. Loss of load probability definition
Loss of one generating unit causes the expected risk of loss of power supply $E(t)$, with mathematical expectation defined as [2]:

$$E_i(t) = p_i \cdot t_i$$ (2)

which $p_i$ is the probability of loss of capacity, and $t_i$ is the duration of loss of capacity in percent. Loss of load probability for the entire system is defined as a sum of all mathematical expectations for all units defined as [2]:

$$
\[ LOLP = \sum_{i=1}^{n} p_i \cdot t_i \]  

(3)

2.5. Loss of load probability during scheduled outages

The planner of power generation should schedule planned outages throughout the year, as a result of the generating units ought to be typically maintained and inspected. Short maintenance technique is often updated. If a generating unit experiences a long-forced outage, the annual maintenance schedule for the power system could also be reshuffled to improve system dependability and to decrease the power system production costs [3].

Planned outage needs of power plants sometimes have a circular pattern [4]. The procedure schedules the maintenance of generating units, so accessible generation capability reserve is that the same for all weeks. This sort of procedure has the bottom LOLP.

2.6. Loss of load expectation

The loss of load expectation represents the chance that aggregates won’t be ready the mandatory power consumption. The term LOLE is closely concerning the term LOLP. If the quantity used for the LOLP is expressed within the time units instead in proportion values, the LOLE is obtained rather than the LOLP. Figure one shows yearly load diagram [2].

The limit value of LOLE for a reliable provide is ten hour annually. In some European countries, the limit also can be settled between four and eight hour annually [2]. Most of the U.S. electrical power utilities are designed on the technical assumption that the overall accumulated time of provide interruptions (forced outages) ought to be no over one day in ten years for the developed countries [7]. In Indonesia with National power service commonplace could be a most of three annually for the Java-Bali electrical power system and five days annually for systems outside of Java [5].

Power system with a higher value of a LOLE contains a lack of power charging or the present units are badly disposable.

![Figure 2. Yearly load diagram](Source: Cepin (2011))

2.7 Loss of load expectation definition

Loss of load expectation is obtained mistreatment the daily peak load variation curve. A selected capability outage contributes to the system by associate quantity up to the merchandise of the chance of existence of the actual outage and therefore the variety of time units (week, month or a year). The best application is that the use of the curve on yearly basis. Once employing a daily peak load variation curve on annual basic, the LOLE is in days each year [2].
\[ \text{LOLE} = \sum_{i=1}^{n} p_i \cdot t_i \] (4)

where \( p_i \) is the individual likelihood of capability in outage and \( t_i \) is the period of loss of power offer in days. Once the cumulative probability \( P_i \) is used, LOLE is defined as [2]:

\[ \text{LOLE} = \sum_{i=1}^{n} P_i (t_i - t_{i-1}) \] (5)

LOLE is additionally defined with a likelihood that consumption \( L \) would not throughout operating power capability \( C \). [2]

\[ \text{LOLE} = \sum_{i=1}^{n} P_i (C_i - L_{i-1}) \] (6)

3. Result and Analysis

3.1. Power plant generation system and failure data

This research was conducted at 4 power plants in Suralaya Power Plant, namely Unit 1-4. Before calculating the generator reliability index, it must be known in ability the power capacity of each generator. The following is data on the capacity of generating units 1-4 in the Suralaya Power Plant.

| Unit | Capacity (MW) | Unit | Capacity (MW) |
|------|---------------|------|---------------|
| 1    | 400           | 3    | 300           |
| 2    | 400           | 4    | 400           |
|      | **Total**     |      | **1600**      |

In addition, it is also necessary to know the failure data from each unit in order to calculate the unavailability or force outage rate (FOR) value of each unit. Each unit has a primary machine there are coal feeder, damper, mill, turbine and boiler.

| Unit | MTBF  | MTTR  | Availability | Unavailability |
|------|-------|-------|--------------|----------------|
| 1    | 13564 | 7     | 0.999484194  | 0.000515806    |
| 2    | 2473  | 10    | 0.995972614  | 0.004027386    |
| 3    | 3136  | 4     | 0.998726115  | 0.001273885    |
| 4    | 2055  | 30    | 0.985611511  | 0.014388489    |

3.2. Loss of load probability calculation

The power system is composed of three generating units: 1, 2, 3 and 4, with their power capacity is same respectively 400 MW. The failure chance of every unit is given and also the success probability of each unit is given. The choice for unit failure chance is that the forced outage rate (FOR) or the inaccessibility of the unit. The choice for unit success chance is that the convenience of the unit.

Table 3 shows the outage state enumeration tables, which enumerates all of these states and the probability of each. For example, the probability that no generating unit is in outage, i.e., all units 1, 2, 3 and 4 are in service, is the product of the success probabilities of units 1, 2, 3 and 4. The probability of this state is the product of the unit failure probability for unit 1 multiplied with unit success probabilities of units 2,3,4. The result in monotonically ordered by increasing order of overall capacity of units in outage.
Evaluating the probability of not to supply a 400 MW load demand. The capacity of the four unit system is 1600 MW, the load could not be supplied if capacity of 400 MW or more is on outage 400 MW. The cumulative probability of 400 MW of more in outage is calculated as a data is presented from Table 4 is 0.000505692 + 0.003962337 + 0.001249854 + 0.014304903 = 0.020114119.

Table 3. Calculation outage state enumeration

| Units in Outage | Unit in Service | Capacity in Outage (MW) | Capacity in service (MW) | Probability |
|----------------|----------------|-------------------------|--------------------------|-------------|
| -              | 1,2,3,4        | 0                       | 1600                     | 0.979885881 |
| 1              | 2,3,4          | 400                     | 1200                     | 0.000505692 |
| 2              | 1,3,4          | 400                     | 1200                     | 0.003962337 |
| 3              | 1,2,4          | 400                     | 1200                     | 0.001249854 |
| 4              | 1,2,3          | 400                     | 1200                     | 0.014304903 |
| 1,2            | 3,4            | 800                     | 800                      | 0.00000204  |
| 1,3            | 2,4            | 800                     | 800                      | 0.00000065  |
| 1,4            | 2,3            | 800                     | 800                      | 0.00000738  |
| 2,3            | 1,4            | 800                     | 800                      | 0.00000505  |
| 2,4            | 1,3            | 800                     | 800                      | 0.00000578  |
| 3,4            | 1,2            | 800                     | 800                      | 0.00001825  |
| 1,2,3          | 4              | 1200                    | 400                      | 0.00000002608 |
| 1,2,4          | 3              | 1200                    | 400                      | 0.000000029852 |
| 1,3,4          | 2              | 1200                    | 400                      | 0.000000009416 |
| 2,3,4          | 1              | 1200                    | 400                      | 0.000000073781 |
| 1,2,3,4        | -              | 1600                    | 0                        | 0.00000000038 |

Sum 1

Table 4. Contributions to loss of load probability

| Capacity in Outage (MW) | Probability of determined capacity or more in outage | Time interval of Capacity in Outage (%) | Contributions of loss of load probability |
|-------------------------|-----------------------------------------------------|----------------------------------------|------------------------------------------|
| 0 or more               | 1                                                   | 0                                      | 0                                        |
| 400 or more             | 0.020114119                                         | 61%                                    | 0.012178685                              |
| 800 or more             | 0.00009133                                          | 98.63%                                 | 0.0000900812                             |
| 1200 or more            | 0.000000115695                                      | 100%                                   | 0.00000011157                            |

Sum LOLP 0.012268882 or 1.23%

Table 3 is extended to Table 4 by adding the time intervals of capacities in outage and the contributions to find result of LOLP. To find the time interval, first, it is need the load data per day from one year. The load per day is presented in figure 2. Second, the load per day is sorting monotonically to get yearly load curve. In this curve we can find capacity outage and duration of loss capacity. The capacity outage is finding from difference between installed capacity and load capacity. The completed yearly load curve is presented in figure 3. The duration of loss capacity is finding from interval from first time until intersection of capacity outage at that time. For example for 400 MW outage or more we get time duration is 221 days or equivalent 61% of all of time interval (365 days).
Finally, The LOLP is the sum of contributions of loss of load probability of the Table 4. The LOLP for in this case is 0.012268882 or 1.23%.

![Figure 3. Curve of load per day](image1)

![Figure 4. Yearly load curve](image2)

3.3. Loss of load probability calculation

The loss of load expectation represents the likelihood that aggregates won't be ready the required power consumption. The term LOLE is closely relating to the term LOLP. If the interval used for the LOLP is expressed within the time units instead in proportion values, the LOLE is obtained rather than the LOLP.

In LOLE calculation, the procedure is representing the power system in tables, including capacities, unavailabilities, and availabilities. A daily load diagram is given in figure 5.

The suralaya power plant generation system in this paper consists of four units from ten of the total units operated. Table 1 shows the corresponding generation system data. Figure 5 shows a daily load diagram. Sixteen combinations of generating units in outage power or in service. Notation 0 stands for
outage of corresponding unit in the and notation 1 stands for operating unit in service. The completed outage stages are presented in Table 5.

Table 3 is presented all unit outage combination probabilities are calculated and represented as cumulative probabilities. LOLE index is calculated from multiplication of expected load duration and cumulative outage probability for required state. The LOLE for in this case is 4,48 days.

| Unit 1 | Unit 2 | Unit 3 | Capacity in Outage (MW) | Capacity in Service (MW) | Probability of each capacity | Cumulative Probability |
|--------|--------|--------|-------------------------|--------------------------|----------------------------|------------------------|
| 1      | 1      | 1      | 0                       | 1600                     | 0.979885881                | 1                      |
| 1      | 1      | 1      | 0                       | 400                      | 0.000505692                | 0.020114119            |
| 1      | 0      | 1      | 1                       | 400                      | 0.003962337                | 0.019608427            |
| 0      | 1      | 1      | 1                       | 400                      | 0.001249854                | 0.01564609             |
| 1      | 1      | 0      | 1                       | 800                      | 0.000000204                | 0.00009133             |
| 0      | 1      | 0      | 1                       | 800                      | 0.000000065                | 0.00008929             |
| 0      | 0      | 1      | 1                       | 800                      | 0.000007838                | 0.00008864             |
| 0      | 1      | 1      | 1                       | 800                      | 0.000000505                | 0.00008126             |
| 0      | 1      | 0      | 1                       | 800                      | 0.0000005784               | 0.00007621             |
| 0      | 1      | 1      | 1                       | 800                      | 0.0001825                  | 0.0001836              |
| 1      | 0      | 0      | 0                       | 1200                     | 0.00000002608              | 0.000000115695         |
| 0      | 1      | 0      | 0                       | 1200                     | 0.000000029852             | 0.000000113087         |
| 0      | 0      | 1      | 0                       | 1200                     | 0.000000009416             | 0.000000083235         |
| 0      | 0      | 0      | 1                       | 1200                     | 0.000000073781             | 0.000000073819         |
| 0      | 0      | 0      | 0                       | 1600                     | 0.000000000038             | 0.000000000038         |

| Capacity in Outage (MW) | Probability of determined capacity or more in outage | Time interval of Capacity in Outage (days) | Contributions of loss of load expectation |
|-------------------------|-----------------------------------------------------|-------------------------------------------|-----------------------------------------|
| 0 or more               | 1                                                   | 0                                         | 0                                       |
| 400 or more             | 0.020114119                                         | 221                                       | 4,45220191                               |
| 800 or more             | 0.00009133                                          | 360                                       | 0.032879629                              |
| 1200 or more            | 0.000000115695                                      | 365                                       | 0.00004223                              |

| Sum LOLE | 4,48 days |

3.4. Comparison of index
From the result of LOLP and LOLE calculation, it can be compared with other standard. In this comparison, The Suralaya Power Plant index is below standard from European Countries and US Electric, but is above of developed country like India. If it is compared other power plant in Indonesia still relevant and argue with standard.
Table 7. Comparison of limit index LOLP/LOLE

| Condition                                      | Limit Index LOLP/LOLE                              |
|------------------------------------------------|---------------------------------------------------|
| Suralaya Power Plant unit 1-4                  | LOLP=1.23% LOLE=4.23 days per years               |
| Indonesia National Power Company (PLN)         | 3 days per year (Java-Bali)                       |
| Cepin (2011)                                   | 5 days per year (Outside Java-Bali)               |
| Some European Countries                        | 4-8 h per year                                    |
| Most U.S Electric power utilities             | No more than 1 day in 10 year                     |
| Developed country (Vijayamohanan, India)       | 20-25 days a year                                 |

4. Conclusions
The results obtained in this paper explain that the calculation of the generator reliability index at the Suralaya power plant using the loss of load probability (LOLP) method in 2019 obtained a value of 1.23% and loss of load expectation is 4.23 days. This condition is still accepted as a standard national power company. The reason why the higher values LOLP/LOLE are in 2019 are possibility of Suralaya PLTU has lost its burden, namely for 2 days in a period of 1 year. First in there was a decrease in load on April 10, 2019 to 576 MW. Second the cause of the blackout on August 4, 2019 was the blackout of Two SUTET circuits Ungaran-Pemalang 500 KVA spread to Depok-Tasikmalaya SUTET so that the areas of West Java, DKI Jakarta and Banten were extinguished simultaneously. At that time the load at the Suralaya power plant dropped to 384 MW. To avoid blackouts from happening again, PLN is currently regulating the flow of electricity from Java 7 and Java 8 to West Java. The goal is that the electricity load in West Java can be fulfilled with the electricity flow. In addition it is expected that the company can arrange maintenance schedules that are suitable to the usage load. In terms of generating capacity it is sufficient, only because of force majeure (blackout) which causes a reduced load which increases the LOLP / LOLE index. To Improve transmission lines is generally directed towards achieving a balance between generating capacity and power demand efficiently. In addition, it is also an effort to overcome channeling bottlenecks, improve service voltage and operating flexibility on subsystems used for balancing between subsystems.

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