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Increasing the Reliability of Distribution Systems By Utilizing Mobile Transformer Units

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Abstract: Maintenance of electrical installations continues to be carried out in maintaining reliability of continuity of electricity distribution. Distribution transformer maintenance activities are carried out in a state without voltage. Of course, with condition without voltage, it has an impact on power outages which can reduce reliability value of the distribution system. In 2024, PT PLN (Persero) UP3 Cempaka Putih has carried out transformer maintenance activities at 7 distribution substations with an average outage duration is 155 minutes. At Distributon Substation TP117, transformer maintenance has been carried out using a minimal outage method, namely by utilizing Mobile Transformer Units as mediator for temporary load transfer during maintenance. Total duration of the outage was only 44 minutes with value of SAIDI is 0.035 minutes/customer and value of ENS is 245,084.07 Wh. By calculating the SAIDI and ENS values based on the pure duration of maintenance work, SAIDI value is calculated to be greater, amount 0.102 minutes/customer and the ENS value is 708,515.77 Wh. So it can be determined that the potential reduction for SAIDI value is 65.69% and ENS value is 65.41%. This means that the reliability of the distribution system can increase because the SAIDI and ENS values can be reduced.

Keywords: Transformer Maintenance, Outage Duration, Reliability, SAIDI, ENS

INTRODUCTION

The distribution system is a system that functions to distribute electricity to users which is divided into two parts, namely medium voltage distribution system and low voltage distribution system. Medium voltage distribution system has a working voltage above 1 kV and as high as 35 kV. Low voltage distribution system has a working voltage as high as 1 kV. Medium voltage distribution network starts from substation / power center on a separate system (isolated), in some places it starts from a power plant. The network form can be radial or closed (radial open loop). Low voltage distribution network is pure radial. Electric power connection is the most downstream part of the electric power distribution system. In the electric power connection, the Limiting and Measuring Device is connected which then distributes electricity to the users. PT PLN (Persero) is one of state-owned enterprises whose business type is as a provider of electricity. The operation of electricity distribution that is directly related to

customer (limited to the kWh Meter) is entirely under control of the distribution unit, one of which is PT PLN (Persero) UP3 Cempaka Putih.

Maintenance activities are a routine carried out by electricity providers. The purpose of electrical installation maintenance activities is to extend life time of equipment and maintain reliability in delivering electrical energy continuously. One of maintenance activities carried out by PT PLN (Persero) UP3 Cempaka Putih, among others, is the maintenance of distribution transformers installed in distribution substations. Careful inspection of transformer in operation needs to be done to ensure that transformer is always in good condition. If necessary and can endanger officers, transformer can be turned off so that inspection carried out gets optimal results. With regular and thorough checks, condition of transformer will be known at any time and damage that will cost a lot of money can be avoided. The implementation of distribution transformer maintenance carried out in a state without voltage can cause power outages for customers. The duration of outages caused by distribution transformer maintenance is quite long, namely two to three hours. With this for urban customers who have a more critical mindset and attitude is certainly a problem for electricity providers. Therefore, it is necessary to carry out a maintenance method that minimizes outages so that customer confidence in the services of electricity supply companies can be improved so that the company's image can also increase. In addition, effort to reduce duration of outages can certainly improve the reliability of the distribution system.

Distribution system reliability can be defined as likelihood of a device or system performing that function adequately, for intended period of time, under intended operating conditions, in this sense not only the probability of failure but also its magnitude, duration and frequency are important. In general, reliability is defined as possibility of a system that is able to work in accordance with certain operating conditions within a specified period, in other words, reliability is also called adequacy or availability. A reliability index is an indicator of reliability expressed in terms of probability. A number of indices have been developed to provide a framework for evaluating power system reliability. Distribution system reliability evaluation consists of load point indices and system indices that are used to obtain in-depth understanding into the overall achievement. Factors that affect reliability index in a power system according to the IEEE P1366 standard include:

- Interruption of Supply, namely cessation of service to one or more, as a result of one or more components getting disturbed.
- Outage, which is a situation where a component cannot function as it should, due to several events related to component.
- Outage Duration, which is the period from the time the component begins to experience outage until time it can be operated again according to its function.
- Interruption Duration, which is the time from the start of outage to when it turns on again.
- Observation interval, which is the total time observed on a power system equipment or component with reviews conducted on the equipment assessed in size per year.

Reliability indices that affect distribution transformer maintenance activities are those related to the outage duration factor. One of them is SAIDI (System Average Interruption Duration Index), which is the average duration of outages per customer served. This is determined by dividing the number of all customers who experience outages in the total outage duration by the total number of customers served. Next is the ENS index (Energy Not Supplied), which is a description of the total energy that is not supplied by the power system.

At PT PLN (Persero) UP3 Cempaka Putih there is equipment in the form of distribution transformers whose operation can move places (mobile), called the Mobile Transformer Units. Mobile Transformer Units is a transformer that can be moved and used as a temporary source

of electrical power. Has characteristics with a compact contract, easy to mobilize, and ready to use quickly / immediately. The functions of Mobile Transformer Units include:

- Replace transformer that is disturbed so that electricity does not go out for long.
- Supplying temporary power through medium voltage distribution network.
- Supplying electricity to customers temporarily.

With Mobile Transformer Units device, it is hoped that it can also be used to anticipate a reduction in duration of outages during distribution transformer maintenance. So that efforts to improve the reliability of distribution system related to the SAIDI and ENS indices can be reduced.

METHOD

In this research using quantitative analysis using data in the form of numbers, tables, graphs, and images. Quantitative research method is one type of research whose specifications are systematic, planned and clearly structured from the beginning to creation of its research design. By comparing the maintenance of distribution transformers with minimal outage by using Mobile Transformer Units with the maintenance of distribution transformers in total outage. How to analyze the test result parameters obtained through achievement of SAIDI and ENS values due to the use of Mobile Transformer Units when maintenance of distribution transformers is carried out.

The first data collection technique used in the preparation of this research is direct research at the research site, namely at PT PLN (Persero) UP3 Cempaka Putih to obtain the required primary data. The second is an interview by asking questions to the relevant parties, this is done to obtain secondary data that can reinforce the primary data that has been obtained. The third is documentation, namely by collecting data and documents that serve as evidence related to the object of research. And the last is literature studies from previous research books, lecture material diktat, standards used, and journals related to the material discussed in this study.

RESULT AND DISCUSSION

Distribution Substation TP117

Distribution Substation TP117 is a kiosk type distribution substation with medium voltage network construction in the form of Medium Voltage Cable Lines. Distribution Substation TP117 distributes low voltage electrical energy (380/220 V) to customers and is a type of Public Service Distribution Substation. The number of customers served at Distribution Substation TP117 as many as 255 customers, with a total of customers of PT PLN (Persero) UP3 Cempaka Putih is 316,208 customers.

Distribution Substation TP117 is equipped with two sets of Load Break Switch type electrical cubicles towards Distribution Substations TP13B and TP125 connected by NA2XSEYBY Cable. The Transformer Protection type cubicles are equipped with a fuse link as a medium voltage side safety. The N2XSY cable connects the Transformer Protection cubicle with the primary side distribution transformer, and the NYY cable connects the secondary side distribution transformer with LV Cell. The transformer is an inner pair type and has a power rating of 630 kVA, with average transformer loading is 62.41%. LV Cell is equipped with a disconnector switch and an NH-type fuse for safety the low-voltage side. Each of these installations is connected to the grounding system at Distribution Substation TP117. The substation installation is depicted in a one-line chart of the substation installation based on Figure 1.

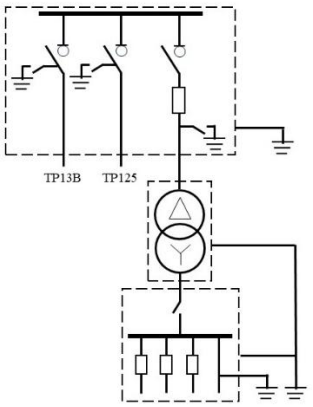

Figure 1. Singel Line Diagram for Installation of Distribution Substation TP117

Mobile Transformer Units

The Mobile Transformer Units is equipped with one distribution transformer unit whose primary side is connected with N2XSY cable and NYY cable connecting the secondary side distribution transformer with LV Cell that has only one department (RSTN) equipped with a NH type fuse with a large current rating, adjusting the secondary current of distribution transformer. The grounding system installed on the distribution transformer body is connected to the distribution substation grounding system. The Mobile Transformer Units used in distribution transformer maintenance activities at Distribution Substation TP117 must be adjusted to the power rating of the distribution transformer as in Distribution Substation TP117, which is 630 kVA. The Mobile Transformer Units installation is depicted in a one-line chart of the substation installation based on Figure 2.

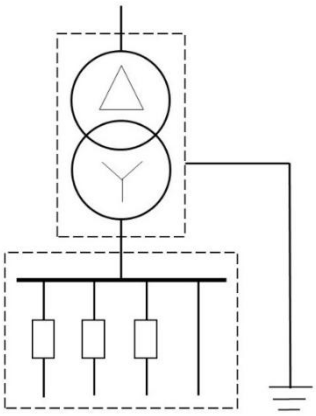

Figure 2. Singel Line Diagram for Installation of Mobile Transformer Units

Distribution Transformer Maintenance

Distribution transformer maintenance has been carried out eight times at distribution substations by PT PLN (Persero) UP3 Cempaka Putih during 2024, equipped with records of outage time and turn-on time to determine the total duration of the outage as shown in Table 1. Distribution Substation TP117 recorded two outages on the same date due to load shifting and load normalization activities due to UTB utilization in transformer maintenance work.

Table 1. Record of Outage Time Due to Distribution Transformer Maintenance

No.	Main Substation	Feeder	Distribution Substasion	Date	Outage Time		Outage Duration (minutes)
					Off	On	
1.	Tanah Tinggi	Pizza	K64B	01/11/2024	10:33	13:20	167

2.	Pulo Mas	Baruna	RM45	02/05/2024	10:12	13:08	176
3.	Gambir Baru	Kuning	K85C	02/27/2024	11:15	13:44	149
4.	Pulo Mas	Kutilang	RM9K	03/14/2024	10:22	13:19	177
5.	Tanah Tinggi	Nagasari	PS12A	05/15/2024	13:41	15:59	138
6.	Pulo Mas	Tekukur	KM46	08/05/2024	10:05	12:08	123
7.	Pulo Mas	Tornado	PG401	10/29/2024	10:34	13:12	158
8.	Tanah Tinggi	Bolu	TP117	12/16/2024	10:23	10:43	20
	Tanah Tinggi	Bolu	TP117	12/16/2024	12:50	13:14	24

Distribution transformer maintenance with the utilization of Mobile Transformer Units carried out at Distribution Substation TP117 consists of 5 stages. The first is the preparation stage carried out before the outage as shown in the Figure 3.

Figure 3. Preparation Stage

The activity stages include:

- Deployment and installation of primary cable (N2XSY) and secondary cable (NYY) to Mobile Transformer Units.
- Installation of Mobile Transformer Units grounding system with Distribution Substation TP117 grounding system.
- Measurement of voltage and current at LV Cell at Distribution Substation TP117.

The second stage is load switching which is carried out in a state of no voltage (load off) with the connection of the Mobile Transformer Units primary and secondary cables to the Distribution Substation TP117 as shown in the Figure 4.

(a) (b)

Figure 4. Load Switching Stage

(a) Primary Cable Connection
(b) Secondary Cable Connection

The activity stages include:
- Operation of the Transformer Protection cubicle at Distribution Substation TP117 for open/close activities
- Disassembly and installation of primary cable (N2XSY) in Transformer Protection cubicle
- Operation of LV Cell switch to open position
- Disassembly and installation of secondary cable (NYY) in LV Cell at Distribution Substation TP117
- Measurement of voltage and current at LV Cell at Distribution Substation TP117

The third stage is the maintenance of distribution transformers carried out in a state without voltage with the condition that the load has been transferred to Mobile Transformer Units, as shown in the Figure 5.

Figure 5. Utilization of Mobile Transformer Units On Transformer Maintenance

The activity stages include:
- Disassembly and installation of primary cable (N2XSY) and secondary cable (NYY) on transformer at Distribution Substation TP117
- Bushing Seal Replacement
- Purification of transformer oil
- Distribution transformer oil breakdown voltage testing
- Distribution transformer insulation resistance testing
- Tightening of bolts and cleaning of the outside of the distribution transformer

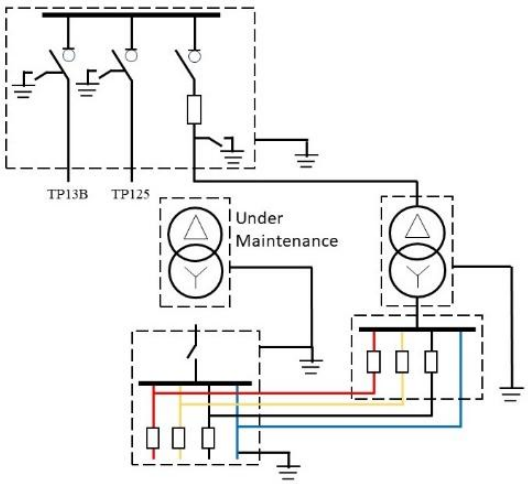

Figure 6. Singel Line Diagram of Utilization of Mobile Transformer Units On Transformer Maintenance

Figure 6 shows a single line diagram of the power network when Mobile Transformer Units utilization on transformer maintenance at Distribution Substation TP117 is carried out, that is with the Mobile Transformer Units input connected from the Transformer Protection cubicle and its output connected to the LV cell of Distribution Substation TP117, as a diversion of the transformer load that goes out (maintained) temporarily during the maintenance process.

The fourth stage is the load normalization stage which is carried out in a no-voltage state (load off), with the stages of activity being more or less the same as the load switching stage. And the last stage is the tidying up stage whose series of activities are the dismantling of primary cables, secondary cables, and grounding systems at Mobile Transformer Units, and cleaning environment of the Distribution Substation TP117. After maintenance activities are carried out at distribution substation TP117, there are records of the duration of activities for each stage of work. With the determination of the duration of outages in load switching and load normalization activities as shown in Table 2.

Table 2. Duration of Distribution Transformer Maintenance Activities

No.	Activity Stage	Duration (minutes)	On Load	No voltage (load off)	No voltage (load switched)
1.	Preparation	30	√		
2.	Load switching	20		√	
3.	Maintenance of distribution transformers	127			√
4.	Load normalization	24		√	
5.	Tide up	40	√		

Comparison of Outage Duration

Based on Table 1,

r_{i1} = Average duration of outage due to transformer maintenance at a number of distribution substations that do not utilize Mobile Transformer Units (total outage).

$$r_{i1} = \frac{167 + 176 + 149 + 177 + 138 + 123 + 158}{7} = \mathbf{155\ minutes}$$

r_{i2} = Outage duration due to transformer maintenance at Distribution Substation TP117 (minimal outage)

r_{i2} = 20 + 24 = **44 minutes**

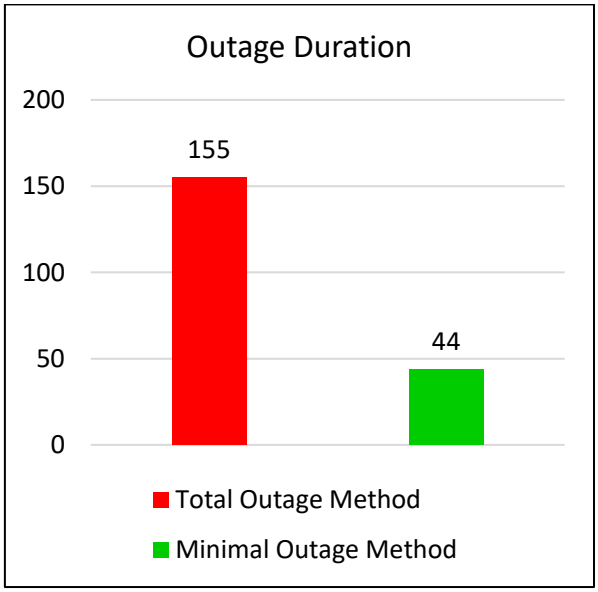

Figure 7. Chart of Outage Duration Comparison

Based on Figure 7, shows a comparison of the duration of outages between distribution transformer maintenance work that does not utilize Mobile Transformer Units and distribution transformer maintenance work that utilizes Mobile Transformer Units carried out at Distribution Substation TP117, with a r_{i2}:r_{i1} comparison value of 44:155 and a percentage decrease of 71.61%. As a result, the duration becomes shorter and is still within the time limit determined by Permen ESDM No. 18 of 2019 concerning Service Quality Level, which is a maximum of outage duration or interruption is 1 hour per month.

Calculation of SAIDI Index

Based on Table 2,

r_{i1} = Duration of work with no voltage under load-off conditions

r_{i1} = 20 + 24 = 44 minutes

Within:

N_i = Number of customers served at Distribution Substation TP117

N_T = Total customers of PT PLN (Persero) UP3 Cempaka Putih

Then the $SAIDI_1$ value can be determined:

$$SAIDI_1 = \frac{\sum r_{i1} \,.\, N_i}{N_T} = \frac{44 \,.\, 255}{316{,}208} = \textbf{0.035 minute/customer}$$

If the transformer maintenance work is carried out without utilizing Mobile Transformer Units, based on Table 2,

r_{i2} = Duration of work with no voltage in the switched load condition

r_{i2} = 127 minutes

Then the $SAIDI_2$ value can be determined:

$$SAIDI_2 = \frac{\sum r_{i2} \,.\, N_i}{N_T} = \frac{127 \,.\, 255}{316{,}208} = \textbf{0.102 minute/customer}$$

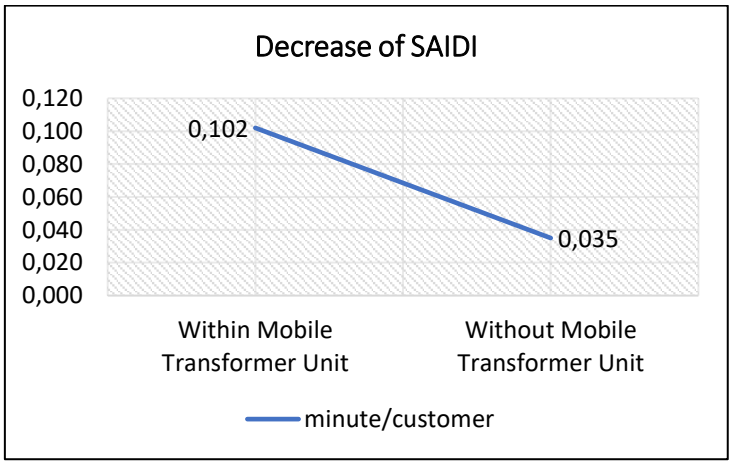

Figure 8. Chart of SAIDI Decrease

Based on the chart in Figure 8, it shows the potential reduction in SAIDI value based on transformer maintenance work at Distribution Substation TP117 by:

$$\left(1 - \frac{SAIDI_1}{SAIDI_2}\right) \times 100\% = \left(1 - \frac{0.035}{0.102}\right) \times 100\% = \textbf{65,69\%}$$

This shows an increase in reliability with a SAIDI value that can be reduced. The achievement of the SAIDI value is also still below the IEEE std 1366-2003 standard, which is 2.3 hours/customer/year or 11.5 minutes/customer/month.

Calculation of ENS Index

Based on Table 2,

r_{i1} = Duration of work with no voltage under load-off conditions

r_{i1} = 20 + 24 = 44 minutes = 0,73 h

Within:

S = 630,000 kVA x 62.41% = 393,183 VA

$L_{avg.i}$ = S x cos phi = 393,183 x 0.85 = 334,205.55 W

Then the ENS_1 value can be determined:

$ENS_1 = \sum L_{avg.i} \times r_{i1}$ = 334,205.55 x 0.73 = **245,084.07 Wh**

If the transformer maintenance work is carried out without utilizing Mobile Transformer Units, based on Table 2,

r_{i2} = Duration of work with no voltage in the switched load condition

r_{i2} = 127 minutes = 2.12 h

Then the ENS_2 value can be determined:

$ENS_2 = \sum L_{avg.i} \times r_{i2}$ = 334,205.55 x 2.12 = **708,515.77 Wh**

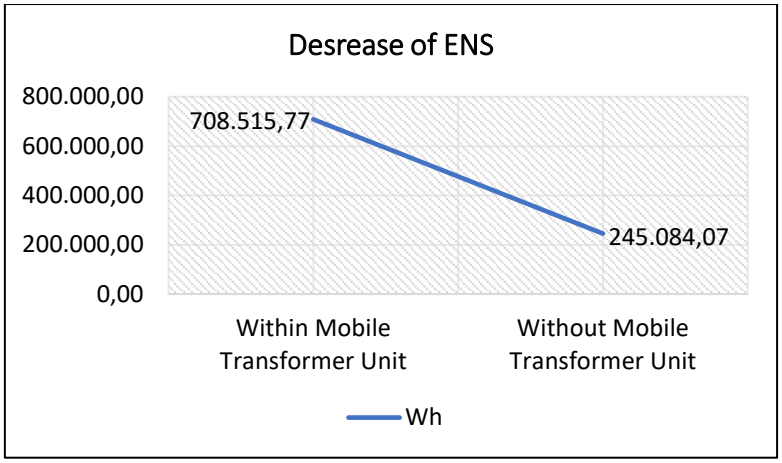

Figure 9. Chart of ENS Decrease

Based on the chart in Figure 9, it shows the potential reduction in ENS value based on transformer maintenance work at Distribution Substation TP117 by:

$$\left(1 - \frac{ENS_1}{ENS_2}\right) \times 100\% = \left(1 - \frac{245{,}084.07}{708{,}515.77}\right) \times 100\% = \mathbf{65.41\%}$$

This shows an increase in reliability due to the ENS value that can be reduced. Internally, PT PLN (Persero) UP3 Cempaka Putih targets ENS achievement of 74.76 MWh per year or 6,230 kWh per month. This shows that the achievement of the ENS value is still below the company standard.

CONCLUSION

Based on the data, calculations, and analysis discussed, the following conclusions can be drawn:

1. Transformer maintenance activities at Distribution Substation TP117 with UTB utilization are carried out in 5 stages, namely: Preparation, Load Switching, Maintenance Implementation, Load Normalization, and Tidying. The minimal outage method is carried out by switching the load of the TP117 Distribution Substation transformer to the UTB transformer for the duration of the maintenance.
2. The outage duration based on transformer maintenance work at distribution substations in total outage (not utilizing UTB) in 2024 is 155 minutes on average. The outage duration

based on transformer maintenance work at Distribution Substation TP117 totals only 44 minutes. Based on the Service Quality Level standard set by Permen ESDM No. 18 of 2019 that the duration of outage due to interference / maintenance is 1 hour per month, the results are better and below the standard. The minimal outage method applied is also calculated to be faster in the duration of the outage with a percentage reduction of 71.61%.

3. The SAIDI value based on transformer maintenance work at Distribution Substation TP117 is 0.035 minutes/customer. If calculated based on the pure duration of transformer maintenance implementation, the value is greater at 0.102 minutes/customer. The SAIDI standard based on IEEE std 1366-2003 is 2.3 hours/customer/year or 11.5 minutes/customer/month, so the SAIDI value achievement is considered good and still below the standard. There is also a potential decrease in SAIDI value by 65.69% which can improve distribution reliability if UTB utilization continues to be applied to every distribution transformer maintenance job.
4. The ENS value based on the transformer maintenance work at Distribution Substation TP117 is 245,084.07 Wh. If calculated based on the pure duration of transformer maintenance implementation, the value is greater, namely 708,515.77 Wh. Based on the internal target of PT PLN (Persero) UP3 Cempaka Putih that the maximum ENS value is 74.76 MWh per year or 6,230 kWh per month, the achievement of the ENS value is considered good and does not exceed the company's target. There is also a potential decrease in ENS value by 65.41% which can improve distribution reliability if UTB utilization continues to be applied to every distribution transformer maintenance job.

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