Analysis of the power transformer condition assessment in PLN Western Java Transmission unit

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Abstract. Transformers are critical equipment of the electrical power supply system and the most expensive asset in the electric power transmission network. Therefore, power transformer condition assessment method is needed to determine the actual condition of power transformer on operating. Indeed, they are several methods of condition assessment for power transformers have been implemented. The transformer data is divided into different levels and parts, so multi-parameter analysis is carried on both by direct condition data and by indirect computing history data. Some method use only one-step process, while others through many stages. This paper proposes a power transformer condition assessment with three stages. First step are Health Index and Susceptibility. Second step is Probability of Failure, that is combination between Health Index and Susceptibility. The last stage is Risk Based Priority as a result of combining Probability of Failure and Criticality Level. The outputs of condition assessment are analysis lifetime prediction, abnormality, recommendations for next action and determine maintenance or replacement priorities. This study has investigated 303 units of power transformers in Western Java Transmission unit. The result of study is useful for the utility company to improve their transformers asset quality.

1. Introduction

The worldwide demand for energy will rise due to the developments of power generation in industrial, service, and residential sectors. A healthy power system is very important to guarantee continuous electricity supply to the end users and this can be achieved through asset management. Transformers are important equipment of the electrical power supply system. A transformer defect can lead to heavy damage in the equipment itself as well as to its surroundings. Therefore, an assessment condition is needed to examine the operating condition of transformers and their real-time performance [1]. Some research proposed Health Index method provides a comprehensive transformer condition assessment within various techniques [2-4]. Others focused to the technical measurements such as UV-Spectrometry [5], dissolved gas analysis (DGA) IEC 60599 [6], an on-load tap changer (OLTC) test [7], a transformers’ winding condition [8] and so on. There is estimated of 21 test methods to assess the overall condition of transformer [9].

Instead of technical method, some research developed “a process” method to evaluate the transformers condition. An evidential reasoning (ER) approach has been introduced to combine evidences and deal with uncertainties [10]. Health Index method is most often used tool for providing a comprehensive condition assessment [3,11,12]. Condition based maintenance using FMEA and FMECA is also basis for the assessment of transformers [4,11]. A condition assessment model of
power transformer based on fuzzy evaluation method and information fusion technology is helpful for improving the accuracy and timeliness of transformer condition [13]. Those process methods have been proven well to assess power transformers condition based on the term and certain condition. To analysis power transformers condition, power transformers condition assessment method must include various parameters so that the analysis becomes more accurate. The method will combine both technical measurement and process approach. Furthermore, this paper wants to elaborate some methods within three steps of process. Each process will utilize one or more technical measurement.

2. Power transformer condition assessment method
Several methods of condition assessment for power transformers have been implemented. This paper proposes a power transformer condition assessment with three stages. First step are Health Index and Susceptibility. Second step is combination between Health Index and Susceptibility, producing Probability of Failure. The last stage is Risk Based Priority as a result of combining Probability of Failure and Criticality Level.

2.1. Health index
The Health Index (HI) represents a practical tool that provides the overall health of the asset, among which reasonably determine the weight of each index is the key to guarantee the quality evaluation. Input data used on HI are result of inspection level 1, inspection level 2 and inspection level 3. Its value has three scores; 9, 6, 1. Score 9 is good, 6 is for moderate and 1 is representing bad condition. The output uses the logic “OR”. It means that the value obtained as a result of Health Index is the lowest / worst value, as figure 1.

![Figure 1. Diagram scoring health index with logic “OR”.

2.1.1. Inspection level 1. Inspection level 1 is a visual inspection in operating condition (in-service inspection). Inspection level 1 purposes is to detect early abnormalities that might occur in the physical transformer without using a measuring instrument. To measure it, can be done by body’s sense like ears for hearing buzzing, nose for smelling burn, eyes to seeing any leakage and skin for feeling cold on one side of the radiator. For inspection level 1, the information will be obtained are:
- Warning of an anomaly and suggestions for simple repair
- Further testing and measurement needed

The score value of the inspection is 1 or 9; it depends on the physical condition of power transformer. The worst-case can occur when an anomaly affect power transformer physically like a leaking, bad wire, broken fan or other supporting equipment’s and so on. Its score will be 1. If power transformer is looks like on perfect physical appearance, it will have score 9.
2.1.2. **Inspection level 2.** At this level, the data obtained is the result of online testing of the transformer. It is measured whether by some technical equipment or testing method include thermovision, DGA analysis, oil quality, and furan test. The value limit is determining the score refers to PLN’s internal standard (in this case, Director Decree No. 0520-2/DIR/2014) as seen on Table 1-3.

**Table 1.** DGA score.

| Dissolved Key Gas Concentration Limits (ppm) | Status | Hydrogen (H2) | Methane (CH4) | Acetylene (C2H2) | Ethylene (C2H4) | Ethane (C2H6) | Carbon Monoxide (CO) | TDCG | Score |
|--------------------------------------------|--------|---------------|---------------|------------------|----------------|---------------|---------------------|------|-------|
| Condition 1                                | 100    | 120           | 1             | 50               | 65             | 350           | 720                 | 9    |
| Condition 2                                | 101-700| 121-400       | 2-9           | 51-100           | 66-100         | 351-570       | 721-1920            | 6    |
| Condition 3                                | 701-1800| 401-1000     | 10-35         | 101-200          | 101-150        | 571-1400      | 1921-4630           | 1    |
| Condition 4                                | >1800  | >1000         | >35           | >200             | >150           | >1400         | >4630               | 1    |

**Table 2.** Oil quality score.

| Property                              | Recommended Action Limits |
|---------------------------------------|---------------------------|
|                                       | Good | Fair | Poor |
| Score                                 | 9    | 6    | 1    |
| Colour                                | Clear and without visible contamination | Dark and/or turbid |
| Breakdown Voltage KkV)               | >50  | 40-50 | <40  |
| Water Content (mg/kg)                | <20  | 20-30 | >30  |
| Acidity (mgKOH/goil)                 | <0,10| 0,10-0,20 | >0,20 |
| Interfacial Tension (mN/m)           | >25  | 20-25 | <20  |

**Table 3.** Furan score.

| Result (ppm) | Analysis                  | Score |
|--------------|---------------------------|-------|
| <473         | Normal Ageing             | 9     |
| 473-2196     | Accelerating Ageing       | 6     |
| 2197-3563    | Dangerous Zone            | 1     |
| 3563-4918    | High Risk of Failure      | 1     |
| >4919        | End of Expected Life      | 1     |

2.1.3. **Inspection Level 3.** For level 3, the data obtained from offline measurement (shutdown testing). The testing is varying from tan delta bushing, tan delta, winding, and polarization index (comparison result of insulation resistance testing at minute 10 with minute 1). While the value limit for the test refers to PLN’s Director Decree No. 0520-2/DIR/2014. They can be seen on table 4-6.

**Table 4.** Tan delta bushing score.

| Result | Analysis | Score |
|--------|----------|-------|
| <0,7%  | Good     | 9     |
| >0,7%  | Bad      | 1     |

**Table 5.** Tan delta winding score.

| Result | Analysis | Score |
|--------|----------|-------|
| <1%    | Good     | 9     |
| >1%    | Bad      | 1     |
Table 6. Polarization index score.

| Result   | Analysis   | Score |
|----------|------------|-------|
| >2,0     | Very Good  | 9     |
| 1.25 – 2.0 | Good      | 9     |
| 1.1 – 1.25 | Questioned | 6     |
| 1.0 – 1.1 | Bad        | 1     |
| < 1.0    | Dangerous  | 1     |

2.2. Susceptibility

Input data used in Susceptibility are load history and age of power transformer. The norm for processing parameters of Susceptibility refers to formulas in three conditions. Good condition is 9, moderate is 6 and bad condition is 1. The output of susceptibility is a score (9,6,1) by calculating the average value or the total Susceptibility parameters (table 7). Index of each parameter is added up, and then it is calculated on average. After that, it is converted again to a score of 9, 6, or 1 referring to table 8.

Table 7. Norm on susceptibility parameters.

| Parameter | Norm | Index | Limit   |
|-----------|------|-------|---------|
| Load      | 9    |       | \leq 100\% |
|           | 1    |       | \geq 100\% |
| Age       | 9    |       | \leq 20 \text{ years} |
|           | 1    |       | > 20 \text{ years} |

Table 8. Susceptibility score.

| Average Value | Score |
|---------------|-------|
| 7 – 9         | 9     |
| 3.5 – 7       | 6     |
| \leq 3.5      | 1     |

2.3. Probability of failure

Probability of Failure, a common term on risk analysis. In this case, Probability of Failure is defined as a combination between Health Index and Susceptibility in a matrix. While the value of both Health Index and Susceptibility are 9,6,1, then the value of Probability of Failure are classified as A, B, C, D and E zone (see figure 2). Thus the matrix has 12 possible scenarios of Probability Failure.

Figure 2. Matrix probability of failure.
2.4. Risk based priority (RBP)
It is a matrix comparing Probability of Failure with Substation Criticality Level based on x-y axis. The Substation Criticality Level is defined based on how important the substation primarily due to its position at the grid or customers. Then the Substation Criticality Level is classified as follows:

- Level 1: for regular area which is ordinary settlement
- Level 2: for high-level consumer regions
- Level 3: near the power plant
- Level 4: in Zero Down Time, VIP and Backbone areas

The output of RBP is the risk priorities of transformers. By combining 4 scenarios of the substation criticality level with 5 zones of the probability of failure, RBP has 20 possible events. Those events are clustered to 4 risk priorities which is the highest risk is R1 and the lowest one is R4 (see figure 3).

![Figure 3. Matrix risk based priority.](image)

Based on all methods, then an assessment condition of power transformers will start from the probability of failure calculating both susceptibility and health index. Therefore its result is compared to the substation criticality level for determining the risk priority for each power transformer. The diagram of the assessment condition for transformers can be seen on figure 4.

![Figure 4. Power transformer assessment condition diagram.](image)

3. Analysis of the power transformer 150/20 kV assessment
As the major player in Indonesian electricity market and the only one company which owns the high voltage transmission networks, recently PLN operates and maintains about 1.964 units of power transformers around Indonesia with the total capacity is 131.164 MVA. The largest system is in Java
Bali grid consist of 500 kV (69 units), 150 kV (1,007 units) and 70 kV (128 units) with the capacity is 95.183 MVA. Due to time limitation, for this study, the condition assessment is conducted at Western Java Transmission unit covering 303 150/20 kV power transformers. The result of power transformers assessment can be discussed for each stage in detail.

The first tier of condition assessment consists of Health Index and Susceptibility. Health Index measurement shows that 118 transformers or 39% has score 9, 55 units (18%) at 6 and 130 units or 43% of all transformers get score 1. While susceptibility aspect shows that 72% or 218 of transformers at 9 and 28% (85 units) have score 6 (see figure 5 and 6). The results confirm that most transformers are still in good performance.

For the next tier, the Probability of Failure, the result of assessment shows that 97 power transformers on A zone, 65 units on B, 88 units on C, and 53 units in D position (see figure 7). It means none of power transformers in Western Java unit is in “danger” condition (E zone). Nevertheless, they are 17% of all transformers (53 units) is already on “alert” condition. The pro-active countermeasure should be noticed for this finding. Then the last stage is Risk Based Priority showing those 47 units in R1 condition, 140 units in R2, 19 units in R3 and 97 units of transformers in R4 condition (see figure 8). The result displays similar finding with the second stage test. Eventually, this study found that 15% of Western Java Transmission units need urgent recovery action. After further technical analysis, 17 units of transformers only need minor maintenance or repair such as oil seepage and cooling fan problems. However, 30 other units need further investigation related to the DGA test, oil quality, tan delta, and polarization index test.

Figure 5. Health index score.  
Figure 6. Susceptibility score.  
Figure 7. Results of probability of failure.  
Figure 8. Results of risk based priority.
4. Conclusions

Proper asset management will allow asset managers to conduct quality assessment of conditions of the electrical assets such as transformers. The execution of power transformer asset management involves an investigation of power transformer's condition by employing Transformer's Health Index. This tool provides automated measurement evaluation, generation of diagnostic statements as well as the determination of power transformers overall condition. Indeed there are several methods of condition assessment for power transformers have been implemented. This paper has proven well a condition assessment with three stages is effective and suitable for hundreds of power transformers implementation. First step are Health index and Susceptibility. The Health Index consists of 8 tests: Visual Inspections, Thermo-vision, Dissolved Gas Analysis (DGA), Oil Quality, Furan, tan delta bushing, tan delta winding, and insulation resistance. Susceptibility is determined by the load history and age. Second step is combination between Health Index and Susceptibility producing the Probability of Failure. The last stage is Risk Based Priority as a result from combining Probability of Failure and Criticality Level.

This study found some anomaly occurs at some power transformers in Western Java Transmission unit. Based on three steps measurement, this assessment method used combines various parameters, such as visual inspection, online testing, offline testing, age, loading, and location of substations will have a more accurate analysis. This study also found that score 1 in Health Index, it does not mean that must change power transformer immediately. Others finding is that the risk priority is effectively helping management and the maintenance teams determine which power transformers should be followed up immediately. So the risk blackouts due to that transformer can be avoided. The result of study is useful for owner to improve their asset’s performance and quality, especially power transformers. Further research is recommended to compare this method with other multi-stages condition assessment for the same or different context.

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