Investigation of high voltage ACSR transmission line dead end connector fault

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Abstract. Transmission line plays important roles in delivering electric energy from generation site closer to the customer. Failure of a transmission line can cause significant economic loss due to undelivered energy and may lead to catastrophic system black out. One critical part of transmission line is dead end connector, thus ensuring good condition of transmission line dead end connector is critical to avoid extensive losses. This paper investigates the cause of failure of dead end connectors that were installed in 150 kV ACSR lines. The failed connectors were examined and tested to find out the cause of the breakdown. Several samples of suspected bad connectors are also tested for comparison. Simulations using finite element software were conducted to provide broader insight on failure propagation. The investigation found that the dead end connectors were failed due to high current flowing through the steel part of the conductor which is caused by high contact resistance between the aluminium part of the conductor and the connector. Further study is needed to mitigate similar condition to occur in the dead end connector installation.

1. Introduction

Transmission line is an important component in a power system and plays the role of transmitting electric power from generator units over a long distance to the customers. Transmission line failure can cause fatal loss for the electric utility due to undelivered energy to the customer or even may lead to catastrophic black out. While transmission line mainly consists of spanned conductors, connectors that joint each span of conductors or provide mechanical support at the dead end plays important roles to ensure the continuity of the lines. However, connectors are considered as one of the weak points in the transmission line and are very prone to failure.

This study aims to investigate the cause of dead end connectors for ACSR type conductor that are installed in high voltage transmission line system in PLN. The type of connector that is being investigated is the two die connector. Connector type and illustration for connector installation are given in figure 1.
2. Methodology
To investigate the cause of the dead end connector failure, several steps are conducted in this study. The first step is to examine samples of faulted dead end connector that leads to high voltage transmission line failure that occurs recently. The geometrical dimension of the conductors paired with the faulted connectors were measured together with the tensile strength of both aluminum and steel component of the conductors. The measured value then compared to the allowable value required in the applicable standard. Thereafter, the faulted connectors were cut to examine the cross section area of the connectors and provide insight on the condition of internal parts of the connectors.

Secondly, several suspected bad connectors were also examined for further comparison. The connectors were tested using micro-ohm meter to measure the contact resistance. Afterwards electric current were injected through the connectors to measure current induced temperature rise of the connectors. To visualize the temperature distribution and hotspot in the connectors, thermal image of the connectors during temperature rise test are captured.

For broader insight, the model of dead end connector was built using finite element method software and then simulated. Simulations were conducted for different value of current and contact resistance. Temperature distribution for each simulation was evaluated, together with current distribution.

3. Result
3.1. Faulted connectors examination
Result of geometrical dimension and tensile strength measurement of the conductor connected to the faulted connectors are given in table 1.

| Parameter                                | Unit    | Measurement (average) | Standard (min; max; nominal) |
|------------------------------------------|---------|-----------------------|------------------------------|
| Outer aluminium strand diameter          | mm      | 3.43                  | 3.41; 3.485; 3.45            |
| Inner aluminium strand diameter          | mm      | 3.426                 | 3.41; 3.485; 3.45            |
| Steel component strand diameter          | mm      | 2.7                   | 2.64; 2.72; 2.68             |
| Outer aluminium strand tensile strength  | N/mm²   | 90.64                 | Min 157                      |
| Inner aluminium strand tensile strength  | N/mm²   | 104.8                 | Min 157                      |
| Steel component strand tensile strength  | N/mm²   | 1501                  | Min 1245                     |

From table 1 we can see that the diameter of both aluminum and steel part of the conductor are still in the range of standard compliance. The tensile strength of the aluminum strands both outer and inner layer has shown significant degradation compared to standard requirement while on the other hand, steel component tensile strength is still above the standard requirement.

Result of the cross section cutting of the dead end connector shows the internal condition of the connector which shown in figure 2.
Figure 2. Cross section cutting of the faulted dead end connector.

From Figure 2 we can see that the ACSR type conductor that is installed to the connector has severe sign of degradation and carbonization. We can also see that the steel part was broken off at the extremity section. In addition to that, there is also sign of necking and iron heating.

3.2. Suspected connectors examination

Contact resistance measurement result for the suspected bad connectors and result of temperature rise test are given in table 2 and figure 3 respectively.

| Sample | Contact Resistance Test (µΩ) |
|--------|-----------------------------|
| 1      | 1306                        |
| 2      | 604                         |
| 3      | 1006                        |

Table 2. Contact resistance measurement test result for suspected bad connectors.

Figure 3. Temperature rise test result for suspected bad connectors.

From Table 2 we can see that the contact resistance of all suspected connectors lays between 600 µΩ to over 1000 µΩ. This value is much higher than normal vale for good connector installation which is typically lower than the value conductor resistance of comparable length or in the case of 240 mm² ACSR type conductor is around 60 µΩ [1]. Temperature rise test conducted for the connector shows strong relationship between current and temperature of the connectors. It is also shown that for current injection of 500A, the temperature of the connectors rise to more than 250 Centigrade.

3.3. Finite element method simulation

Model of the dead end connector and simulation result using finite element method software are given in figure 4.
From figure 4 we can see that at low contact resistance (normal condition) most of the current flows from the aluminum part of the conductor and only negligible amount that flows through the steel part. When the connector undergoes degradation process and contact resistance value increases, the amount of current flowing through the steel component increases. This current will cause significant heating at the steel part especially at the extremity part as shown in figure 5.

**Figure 4.** Model and simulation result of dead end connector using finite element method software.

**Figure 5.** Temperature increase at the extremity of steel component.

**4. Discussion**

Aluminium conductor steel reinforced (ACSR) type conductors consist of two components: aluminium component where electric current flows and steel component that provides tensile strength reinforcement. Typically in ACSR type conductor, the tensile load will be shared between the aluminium component and steel component by 40% and 60% respectively, thus the tensile strength of aluminium strand still plays important role in bearing tensile load imposed to the conductor.

From the tensile strength test shown in Table 1 we can see that the tensile strength of the aluminium strands has already decreased. Aluminium strands tensile strength decreasing can be caused by annealing process due to cumulative heating during the operation of the connector [2,3]. The higher the operation temperature, together with the duration of high temperature event, the more annealing process soften the aluminium strands.

Carbonization at the surface of the conductor and the inner side of the connector indicates that prior to connector failure the value of connector contact resistance was much higher than normal condition. As seen from the temperature rise test conducted to the suspected bad connectors, connectors with high value of contact resistance will experience high operational temperature, especially when delivering
high electric load. This high operation temperature will cause alloyed aluminium to anneal and soften. However, the high operation condition only affect the steel part minimally as temperature below 300 oC will not give significant impact to steel tensile properties [4-6].

Generally high operating temperature conditions of connectors are identified with thermal imaging inspection conducted by the linesman. However, several factors need to be considered to gain accurate readings such as ambient condition, current flowing and emissivity [7]. Nevertheless, the maintenance of connectors that have been identified from thermal imaging inspection needs to be executed immediately as excessive heat production from connector is the final stage in connector failure [8]. Investigation of several dead end connector failure shows that some failure locations had been identified from thermal imaging inspection but the connectors fails prior to scheduled maintenance.

High contact resistance in the connector in general affected by two conditions: severe operation condition and high initial contact resistance [9]. When connectors are installed at the transmission line, connectors experience thermal stress and thermal cycling. Thermal cycling will cause the conductor and connector to expand and contract periodically, create gap between conductor and connector which induce oxidation and reduce compression force of connector and also accommodate fretting. Both oxidation and fretting will increase contact resistance value which increases the severity of thermal stress and thermal cycling experienced by the connector [10-12].

One important aspect that caused high initial contact resistance value of connectors is improper cleaning of the conductor before being installed to the connector. Further investigation of several dead-end connector failures raises the concern of the connectors were installed together with old existing conductors. Aluminium surface will have an oxide layer build up which is resistive immediately after it is exposed to the open air [13]. The longer the conductor exposed with open air the more oxide layer built at the conductor surface, together with other polluters. If this oxide layer and polluters are not properly cleaned before installation, it will result in high initial connector contact resistance.

As previously mentioned, high operation temperature at the contact location will not affect the steel component tensile strength. However, from finite element method simulation we can see that apart from hot spot at the contact area, high contact resistance of connector will cause more current to flow through the steel component instead of aluminium part. In severe contact resistance degradation, most of the load current will flow through the steel component instead of through the aluminium component. This current will induce the creation of hot spot at the steel component, especially at the extremity point located at the expansion gap. This simulation finding agrees with the condition obtained from cross section cutting of the faulted connectors where excessive heating mark was found at the extremity point. This hot spot may reach a temperature that reduces the steel strands tensile strength to a point lower than the tensile load applied and lead to connector failure.

5. Conclusion
This study concludes that the dead end connector failure is caused by reduced tensile strength of steel caused by excessive heating from current flowing at the steel part of the ACSR conductor. This is due to high contact resistance between conductor and connector which arguably driven by improper cleaning of conductor and can be identified from thermal imaging inspection. Proper supervision of connector installation and immediate follow-up action of thermal imaging inspection is required to mitigate similar connector failure.

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