STUDY OF CABLE CRIMPING FACTORS AFFECTING CONTACT RESISTANCE OF MEDIUM VOLTAGE CABLE FERRULE AND LUG

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ABSTRACT

In this study, crimping factors that have possibilities to affect the contact resistance of medium voltage cable ferrule and lug had been determined and further verified in laboratory experiments. A good crimping is important in order to achieve a very good contact resistance for cable joint (Below 50micro-Ohms). Other than that, good contact resistance between cables joint can reduce the chance of having hotspots that are commonly caused by overheating in cable joint. It was found in most situations that the measurement of contact resistance at site is not possible due to insufficient access to make a measurement. Most of cable failure cases were caused by failure of cable joints. Hence, a better crimping or cable connection method is needed to ensure a good contact in every cable joint. There are few crimping factors that have been pondered in this study and the factors are; (1) Crimping pressure, (2) Number of crimp indents, (3) Location of crimp indents, and (4) Shape of crimp indents. Twenty eight different configuration of compression connectors and bolted connectors for 240 mm2 stranded aluminium cable conductors have been examined in order to identify and clarify the correlations between the designs characteristics, applied pressure, configurations, crimp numbers and other possible parameters to the quality of the connection of ferrule and lug. The quality is assessed with the basis in contact resistance measurement and tensile strength after sample preparation. The results showed that applied pressure does not necessarily contributed to increase of contact resistance, but configuration and crimp numbers does. These results also showed that deep indent crimp is better than hexagonal crimp for 240 mm2 stranded aluminium cable conductors and how different deep indent crimp in terms of quality compared to the increasingly popular mechanical connectors.

Keywords: Aluminium power conductors, connectors, deep indent crimping, hexagonal compression, bolted connectors, contact mechanical factors, contact resistance, power cable connection, mechanical strength of connection, tensile strength, maximum load, testing

INTRODUCTION

Jointing ferrule is one of the major components of the cable jointing kit. Crimping ferrule has commonly been used as the connector for straight-through underground medium voltage cable joints. A good cable connection shall result in very good contact resistance, hence avoiding hotspot due to overheating. Theoretically, the contact resistance of the ferrule should be measured after ferrule installation in order to determine good contact between conductors.

Nevertheless, the measurement of contact resistance at site is not possible due to insufficient access to do the measurement & unavailability of micro-ohmmeter. Hence, an alternative method has been required to ensure the good contact of the cable connection achieved. Crimping factors e.g. crimping pressure, depth & shape of indentation, area & number of indentation etc, had been identified to have effect on contact resistance shall be studied, to determine its influence to contact resistance value.

Based on paper entitled "*Aging of Defective Electrical Joints in Underground Power Distribution System*" by Daniel Fourier, it was stated that; the value of contact resistance that can be considered as good electrical contact is 15 micro ohms. In that study also he found that in order to get the desired contact resistance, for crimping ferrule, 8000 psi pressure need to be applied during crimping and 75Nm torque need to be applied during bolt fastening.

Two of the most popular connection method in jointing underground medium voltage cables are by using compression connectors and bolted connectors. The most popular of compression connectors are hexagonal compression and deep indent crimping. While for bolted connectors, it is widely known as mechanical connectors.

For hexagonal compression and deep indent crimping connectors, the conductors to be joined are fed into a hollow cylinder or tube, better known as ferrule. There are two common material used to make ferrule which are aluminium and copper. For 240 mm2 stranded aluminium cable conductors, the material commonly used to make ferrule is aluminium. The tools used to make one or more indents or compression can either be hydraulic or mechanical tools. The tool provides the desired force and pressure thus mechanically compressing and deforming the ferrule to the shape as the tool head shaped.

As for mechanical connectors, the bolt is torque is the predetermined factor, which is contstant and the conductor deformation, varies with the conductor properties. Usually, mechanical connectors are made specifically for each sizes of conductor. In recent years, mechanical connectors have become increasingly popular for jointing conductors of insulated cables used for power distribution and transmission. The prime reason is that mechanical connectors in most cases are easier to assemble than hexagonal and deep indent connectors. Usually, only a socket a socket of wrench is required, as opposed to the bulky hydraulic or electrical compression tools needed for most compression connectors

METHODOLOGY

Sample preparation

All the connection samples are using the same 240 mm2 stranded aluminium cable conductor. All conductor samples were cut in the same length of 500mm without removing its insulation and jacket. Before jointing, 100mm of insulation and jacket from one end of every conductor sample was removed, leaving only the aluminium conductor left. The conductor's ends were cleaned and laminated with thin plastic wrapping to minimize oxidation of the conductor. The plastic wrapping was removed only when jointing is about to be conducted.

For the connectors, two different TNB commercial supplied ferrule and lug was selected, supplier a and b. The ferrule that was used is a hollow aluminium cylinder with grease on the inner surface. Ferrule a and b are similar in shape but one is slightly thicker than the other. While the lugs are a bi-metal hollow aluminium cylinder with grease combined with copper ring-plate. Lug a and b are also similar in shape and dimension.

As for mechanical connector, there are also two different mechanical connector for ferrule and lug, supplier c and d. The ferrule is a hollow aluminium cylinder with four preset bolts in a "zig-zag" formation. The bolts were made of copper. Ferrule c and d are completely dry, without any grease. And one is slightly bigger than the other. As for the lug, it was a hollow aluminium cylinder with aluminium ring-plate with two preset inline bolts, different to the compression conductor's bi-metal lug. Both ferrule and lug were tightened to the conductor using torque wrench. Both lug c and d are similar in size and is dry, without any grease.

All the ferrules and lugs used were specified for 240 mm2 stranded aluminium cable conductor.

Jointing process

500mm conductor from one same cable drum is used for all samples. Also, the same group of jointer, with the same tools and environment, made the joints. To access the jointing technology, the following configuration types were selected for the experimentation in Phase 1;

- Conventional – current standard practiced by Tenaga Nasional Berhad (Malaysia) to joint ferrule and lug, as benchmark to others.
- Pressure type – variable pressure setting for jointing, to study the effect of pressure to the contact resistance measurement value.
- Indent position – to study if irregular positioning of crimping is contributing to bad contact resistance measurement value.
- Indent number – to see whether increasing or decreasing the number of crimp can improve the contact resistance value.

All twenty-eight configurations above have five samples each. From the tests conducted later on, averaging of results was made from the five sample's results. For compression connections, variable pressure hydraulic crimping tool was used and torque wrench was used for the mechanical connectors.

Table 1: Conventional type configuration

	Applied Pressure	Indent number	Indent formation
No Ferrule	-	-	-
Compression Ferrule	700 bar	4	Inline
Mechanical Ferrule	Torque wrench specification	4	"Zig-Zag"
No Lug	-	-	-
Compression Lug	700 bar	2	Inline
Mechanical Lug	Torque wrench specification	2	Inline

Table 2: Pressure type configuration

	Applied Pressure	Indent number	Indent formation
Ferrule Type 1	700 bar	4	Inline
Ferrule Type 2	600 bar	4	Inline
Ferrule Type 3	500 bar	4	Inline
Ferrule Type 4	400 bar	4	Inline
Ferrule Type 5	300 bar	4	Inline
Lug Type 1	700 bar	2	Inline
Lug Type 2	600 bar	2	Inline
Lug Type 3	500 bar	2	Inline
Lug Type 4	400 bar	2	Inline
Lug Type 5	300 bar	2	Inline

Table 3: Indent position configuration

	Applied Pressure	Indent number	Indent formation

Ferrule Type 1	700 bar	4	↑↓↑↓
Ferrule Type 2	700 bar	4	↑↓↓↑
Ferrule Type 3	700 bar	4	←↑→↓
Lug Type 1	700 bar	2	↑←
Lug Type 2	700 bar	2	↑↓

Table 4: Indent number configuration

	Applied Pressure	Indent number	Indent formation
Ferrule Type 1	700 bar	2x Hexagonal	Inline
Ferrule Type 2	700 bar	4x Hexagonal	Inline
Ferrule Type 3	700 bar	6x Hexagonal	Inline
Ferrule Type 4	700 bar	2x Deep Indent	Inline
Lug Type 1	700 bar	1x Hexagonal	-
Lug Type 2	700 bar	2x Hexagonal	Inline
Lug Type 3	700 bar	1x Deep Indent	-

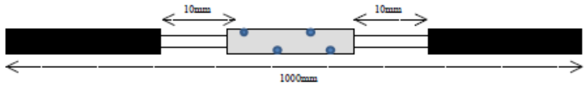

Diagram 7: Indent Position Type 1 – Compression Ferrule

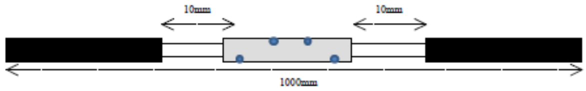

Diagram 8: Indent Position Type 2 – Compression Ferrule

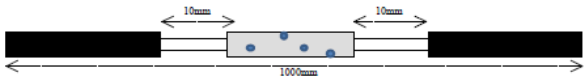

Diagram 9: Indent Position Type 3 - Compression Ferrule

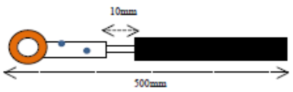

Diagram 10: Indent Position Type 4 - Compression Lug

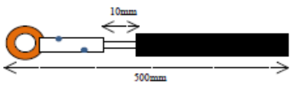

Diagram 11: Indent Position Type 5 - Compression Lug

Figure 1: Samples of different crimping configurations

TESTS CONDUCTED

The following tests were done for all 280 samples;

(1) Contact resistance test
(2) X-ray test
(3) Tensile test

From this study, a correlation between crimping factors and contact resistance reading was established.

Contact resistance measurements were done immediately after the jointing process is being done. The test was done using the same equipment, with the same measurement setting and length of sample measured. The process was continued with x-ray test, to see the area of contact achieved by each samples. After the x-ray test, the samples were later tested for tensile strength. The tensile strength of each sample were determined by its maximum load before break or the conductor disconnected from the connector. For the tensile strength, all sample were tested using the same hydraulic pulling machine with same pulling speed & applied grip.

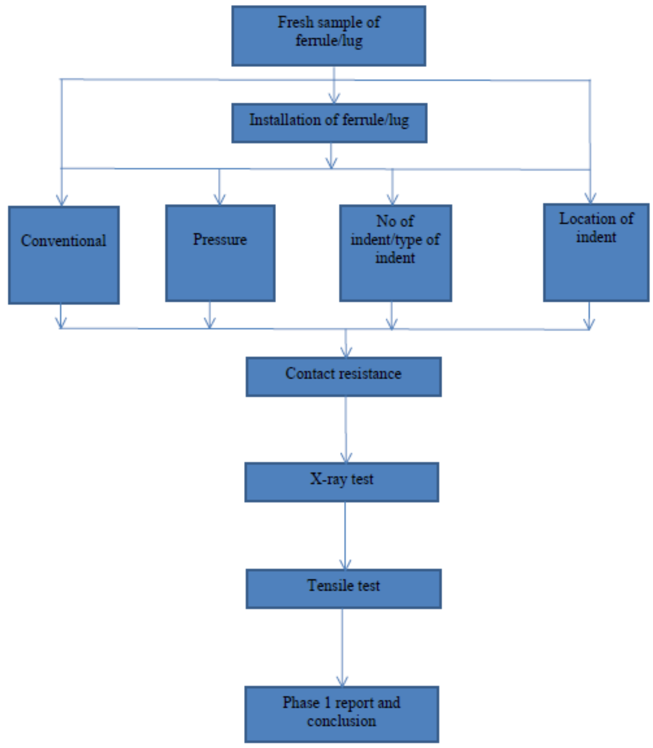

Figure 2: Flowchart of experimentation

TEST RESULTS AND DISCUSSION

From the test results in Table 5, it shows that deep indent crimping can achieve similar contact resistance and also have better tensile strength compared to mechanical connector. Between 700 bar – 400 bar applied pressure as shown in Table 6, the contact resistance and tensile strength of all samples are similar. However at 300 bar applied pressure, the contact resistance is similar to the others but the tensile strength is lower than the others. Different positioning of crimp did improve the tensile strength while maintaining its level of contact resistance value, as shown in Table 7, with exception of Ferrule Type 1. It did shows in Table 8 that hexagonal crimping is not better than deep indent crimping, even with increase number of indent.

Table 5: Conventional type test results

	Contact Resistance Test (μΩ)	Tensile Test (kN)

No Ferrule	6.2	33.6
Ferrule – A	6.4	21.7
Ferrule – B	7.2	23.4
Mechanical Ferrule – C	7.4	11.9
Mechanical Ferrule – D	6.2	19.0
No Lug	1.6	26.6
Lug – A	5.8	19.6
Lug – B	5.4	19.6
Mechanical Lug – C	4.8	16.0
Mechanical Lug - D	6.4	23.6

Table 6: Pressure type test results

	Contact Resistance Test (μΩ)	Tensile Test (kN)
Ferrule Type 1 – A	6.8	21.2
Ferrule Type 1 – B	6.6	22.3
Ferrule Type 2 – A	7.2	21.0
Ferrule Type 2 – B	7.6	22.8
Ferrule Type 3 – A	6.8	21.5
Ferrule Type 3 – B	6.4	22.6
Ferrule Type 4 – A	6.4	20.1
Ferrule Type 4 – B	7.8	23.6
Ferrule Type 5 – A	6.2	18.7
Ferrule Type 5 – B	7.4	20.4
Lug Type 1 – A	5.6	18.2
Lug Type 1 – B	6.6	19.2
Lug Type 2 – A	6.2	19.9
Lug Type 2 – B	6.6	20.0
Lug Type 3 – A	6.2	16.6
Lug Type 3 – B	8.0	19.7
Lug Type 4 – A	6.4	18.8
Lug Type 4 – B	6.8	19.8
Lug Type 5 – A	7.0	17.4
Lug Type 5 – B	7.2	16.3

Table 7: Indent Position type

	Contact Resistance Test (μΩ)	Tensile Test (kN)
Ferrule Type 1 - A	11.8	21.2
Ferrule Type 1 - B	8.8	22.8
Ferrule Type 2 - A	9.0	22.0
Ferrule Type 2 - B	7.4	23.7
Ferrule Type 3 - A	8.8	21.6
Ferrule Type 3 - B	6.8	22.5
Lug Type 1 - A	7.6	17.9
Lug Type 1 - B	7.0	18.5
Lug Type 2 - A	7.0	19.3
Lug Type 2 - B	6.8	18.8

Table 8: Indent Number type

	Contact Resistance Test (μΩ)	Tensile Test (kN)
Ferrule Type 1 - A	8.4	10.0
Ferrule Type 1 - B	8.2	11.0
Ferrule Type 2 - A	7.6	13.9
Ferrule Type 2 - B	9.2	16.8
Ferrule Type 3 - A	7.2	15.7
Ferrule Type 3 - B	7.2	19.8
Ferrule Type 4 - A	7.6	17.5
Ferrule Type 4 - B	7.2	18.9
Lug Type 1 - A	7	9.1
Lug Type 1 - B	7.8	9.9
Lug Type 2 - A	7.2	11.2
LugType 2 - B	6.4	15.9
Lug Type 3 - A	7	14.8
Lug Type 3 - B	7.4	17.2

CONCLUSION

From the contact resistance test & tensile test results, it shows that:

- Contact resistance is not correlated to Tensile strength of ferrule and lug joints.
- Deep indent crimping give the best Tensile strength for ferrule and lug joints for same 240 mm2 stranded aluminium cable conductor.
- Some indent formation can improve the contact resistance value, and some cannot.
- At 400 bar – 700 bar applied pressure to ferrule and lug, the contact resistance and tensile strength is at about the same, but not at 300 bars.

REFERENCE

[1]. N Miswan, H.S. Abd Halim, H Hizam, “Thermal Performance of Ferrule Designs for Medium Voltage Cable Jointing”, Procedings of the 9th International Conference on Properties and Applications of Dielectric Materials, July 19-23, 2009.

[2]. IEC 60502-4, “Power Cables with extruded insulation and their accessories for rated voltages from 1kV (Um=1.2kV) up to 30kV (Um=36kV) – Part 4 : Test requirements on accessories for cables with rated voltages from 6kV (Um=7.2kV) up to 30kV (Um=36kV)”, 2005.

[3]. M.Runde, H.Jensvold and M.Jochim, “Compression Connectors for Stranded Aluminium Power Conductors”, IEEE Transactions on Power Delivery, July 2004, pp. 933-942.

[4]. T.A. Short, “Electrical Power Distribution

[5]. Z.A. Abu Zarim, H.S. Abd Halim and R.H. Mohd Ariffin, “The Study of Ferrule Design and Performance”, TNB Research, Malaysia, Final Report, June 2007.

[6]. D. Fournier and N. Amyot, “Diagnostic of Overheating Underground Distribution Cable Joints”, Proceeding CIRED 2001, IEE Conference Publication no. 482.