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Development of Design Criteria of High Voltage Expansion Connectors Depending On Current and Temperature Distribution

Nurettin ÇETİNKAYA
Selcuk University, Electrical-Electronics Engineering Department, Konya, Turkey

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Abstract: -- **High voltage energy transmissions to minimize the energy losses are made. The connection of high voltage networks, control and supply are made of the most important places where substations. Using this equipment in the field that allows you to move along with the increasing of voltage and high currents, some problems arise. This problem is especially of the currents and the temperature distribution of the materials through the distribution of the material leads to energy losses and hence unavailable about the lack of proper efficient. They also continue to threaten the security of the system. Substations expansion connectors are planned to be developed within the scope of this study aims to reduce energy losses and vulnerabilities as much as possible. In this study, criteria for determining the optimal expansion connector dimensions in accordance with the relevant regulations have been developed and tested for energy sustainability and production ease. As a result, the required connector dimensions and manufacturing conditions have been improved to make the current and temperature distribution uniform.**

Keywords: High current, high voltage, energy transmission, expansion connector.

I. INTRODUCTION

The energy sustainability and security involved in energy management are important requirements of power systems. One of the real application places is the substation. Substations are one of the most important switching and operating places of electrical transmission facilities. That is why substations are confronted as places where measures at the highest level need to be taken in terms of operational safety and especially energy sustainability.

The connection points of the electrical elements in the substations are one step ahead for the safety and continuity of the system. This is because a fault at the connection point may cause failure of the whole plant, thus disabling part or all of the energy transmission line [1, 2]. Therefore, the design, assembly and operation of these parts should be given extreme importance.

For electrical connection equipment to be used at high voltage, ANSI/NEMA CC 1-2009, R2015 standards apply. There are many designs that can be done according to these standards [3-5]. The designs that are performed should reflect the unique ideas of each company and at the same time must comply with the operating conditions within the limits defined by the standard.

The main material of substations is aluminum pipe busbar. High-voltage, high-current equipment is connected to these busbars. The standard production size of the busbar is around 21 m. Expansion connectors are used for the extension of the sizes of these bars. These connectors must be both flexible smoothly to compensate for the elongation and shortening of the bus bars and able to carry high currents.

7, 19, 37, 61 and more wires are made of different high-voltage expansion connectors which enable the connection of the aluminum pipe to the bus using all aluminum conductors (AAC). Standard supply currents of 2000 A and 3000 A are selected as the basis.

The main objectives of this study are; The design of high voltage connectors of 2000 A and 3000 A which provide smooth current, temperature and magnetic field distributions and cause minimum energy loss and at the same time ensure safe working conditions and design criteria. The operating voltage of the terminals to be designed in this study is planned to be maximum 380 kV. The corona ring should also be designed and used for the connectors to be used at higher voltages [6, 7].

II. SUBSTATIONS CONNECTORS STANDARD REQUIREMENTS

The most obvious requirements of the ANSI/NEMA CC 1-2009 standard are explained in this paper. In particular, the temperature increase condition emphasizes that the current distribution should be smooth as well. The five different requirements that the standard requires are briefly described below.

A. Performance requirements

The current carrying capacities [8-10] and phase spacing limit values of conductors and pipes used in this section are given. In addition to this, temperature rise limits are also defined. The temperature rise of a substation connector at rated current shall not exceed the temperature rise of the conductor with which it is intended to be used. The temperature rise of a substation connector that connects conductors of varying sizes shall not exceed the temperature rise of connector having the highest temperature rise. The hot-spot temperature rise shall not exceed the average temperature rise by more than 10 □C. In order to meet this requirement, it is necessary to make the temperature distribution on the connector ideal. In fact, this process helps to keep the current distribution regular.

B. Test methods

Temperature rise tests on electric power connectors shall be conducted either indoors or outdoors, at the manufacturer’s own discretion. The temperature rise shall be determined at 100%, 125%, and 150% of the nominal current, with equilibrium temperatures obtained at each level. Equilibrium temperature is defined as a constant temperature between three successive measurements taken five minutes apart. Measurements shall be made at the end of the first 30 minutes and at one-hour intervals thereafter until completion of the test.

To eliminate heat sinks or hot situations on the test loop, conductors shall have a length from each opening of the connector to the point where the connection is made to the circuit of at least 8X of the conductor diameter, but not less than 1.2 m [11, 12]. This requirement is fulfilled in the experimental set.

C. Design requirements

Aluminum alloy bolts shall be used on aluminum alloy conductors. Alternate alloy materials, including stainless steel, shall be permitted to be used for bolts if performance requirements are met and no adverse material compatibility or galling of threads occurs and if approved by the manufacturer.

The conductors shall be assembled in the connector and the bolts tightened uniformly and alternately, increments until 50% over the nominal torque value is reached.

D. Recommendation for making connections

The connector and conductor surfaces should be thorough cleaned with a wire brush or emery cloth. A bright surface is needed. A contact compound should be applied right away following the cleaning of the surface. Insulation against ground shall be strictly controlled before power is applied.

E. Marking requirements

The minimum two information following shall be given on all electric power connectors; firstly manufacturer's description and secondly nominal size or range of sizes of the conductors with which the connector is intended to be used. The size of a substation connector shall be marked according to bus or conductor to be connected.

III. EXPERIMENTAL DESIGN AND SETUP

A. Experimental Set

The test setup designed for the application is shown in Figure 1. When the test setup was designed, the length of the aluminum buses used to minimize the magnetic field effects was tried to be selected as long as possible. The busbar size which should be used in the test sets is generally recommended as 5 m. The actual length of the buses in the real transformer center is around 20 m.

Buses sections are manufactured in sizes 114/6, 114/10 and 220/8 as standard. The first number used in the sizing defines the diameter and the second number defines thickness in mm. At least 4 bolts are used for good contact of the bus connections. Wooden base and ceramic feet are used for insulation. The current source can provide up to 10.000 A alternating current (AC). Rogowski coils are used to measure the currents flowing through the aluminum buses and the conductors in the connector.

Figure 1: Experimental set appearance

B. Technicial Specifications of Tested Products

How the aluminum conductor reacts in the casting depending on the total waiting time and the application temperature is also very important for the manufacture of the connector. If the designed connector resistance is lower than the busbar resistance, the operating temperature will naturally be lower. To achieve this, it is necessary to use a larger equivalent of aluminum alloy. Conductivity coefficients of aluminum bars and alloys are the most important factor in this evaluation. The formation of a complete electrical conduction between the aluminum conductors and the casting concerns the current carrying capacity of the connector. Two different applications have been carried out to explain this situation. At first, the reactions of the conductor at different temperatures and durations are measured. This study is shown in Figure 2. The material used in this study is AAC (All Aluminum Conductors) conductor at 61x3.78 (684.5 mm2) section called Columbine. The standard melting temperature for aluminum is known to be 660 °C [9, 10]. The values above this temperature can be used as aluminum liquid and can be poured into a suitable mold to get the desired shape. Once solidified, it can be removed from the mold. During actual manufacturing, between 5 and 10 minutes, the conductors become the connector by waiting in the casting at about 700 C. It can be said that welded connectors may be better for conductors with a number of turns of 61 or more. The temperatures and times applied to the conductors shown in Figure 2 are given in Table 1 below.

Figure 2: Temperature test for aluminum conductors

Table 1. Temperature and Duration Test

Conductor Number	Applied Values	
	Temperature (°C)	Duration (s)
1	800	10
2	750	5
3	800	8
4	750	3
5	720	3
6	700	1

Secondly, the actual state of the casting is investigated by cutting a product made into a connector. The front view and cut-away parts of a connector cut are shown together in Figure 3 and Figure 4, respectively. Generally it is seen that the cast conductors are completely grasped but not melted. Even a contact of a conductor is not fully contacted. The biggest reason for this is; because the distance between conductors is not enough, the casting cannot reach the desired region exactly. Strict contact for electrical conductivity is the most important factor. The casting temperature and duration must be applied correctly to ensure complete contact with the outermost winding of the conductors. It turns out that the application temperature must be over 700 °C for actual manufacturing.

Figure 3: Sectioned sample connector (front view)

Figure 4: Sectioned sample connector (cut-away parts)

IV. IMPLEMENTED CONNECTOR DESIGN

The use rates of the current carrying capacities of the connectors have been calculated as a result of experiments carried out for about one year with different connectors designed as 2, 4, 6, 8, 10 and 12 wires. Current carrying capacity utilization rate; Is obtained by dividing the total actual current value through the connectors designed under the same experimental conditions into the total current carrying capacities of the wires in the connector. Depending on the number of wires; the utilization ratios of the current carrying capacities of the used conductors are given in Table 2.

These usage rates are obtained by dividing the total current of the common connector, by the total nominal current of the wires in the connector when the nominal current flows from the last connector wire. As the number of wires increases, the capacity usage rate decreases.

Table 2. Capacity Utulization Rates (CUR)

Test Number	Wire used		Obtained Values	
	Name	Cross section	Number of wire	CUR
1	Columbine	61x3,78	2	0.95
2	Mistletoe	37x3.11	4	0.83
3	Dahlia	19x4.35	6	0.78
4	Oxlip	7x4.42	8	0.73
5	Laurel	19x3.01	10	0.69
6	Oxlip	7x4.42	12	0.65

This also indicates that less wire designs are better suited for use in current carrying capacities. In designs made with only two wires, the form of the manufacturing may need to be changed. The transition resistance in casting and welding manufacturing is the most important factor. Furthermore, it is necessary to use two different conductors for two different current values.

The temperature distribution of the expansion connector used in this study for two hours 125% load current is shown in Figure 5. It has been seen that the temperatures are higher because more current flows through the conductors on the outside. The more uniform the current distribution, the less the color differences will be. Thus, the first condition for the current distribution and hence the temperature distribution to be uniform is to reduce the number of conductors.

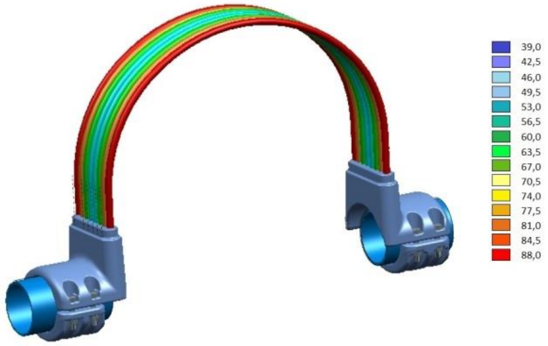

Figure 5: Temperature distribution

For temperature and current distribution to be more uniform, a number of constraints must be defined for the surface where the connector wires are located together. Some of these constraints are explained below.

The cross-section of the connection surface must be at least three times the total cross-section of the wires. Because there is a significant difference between the conductivity coefficient values of aluminum castings and conductors. While the electrical conductivity of the aluminum conductor is around 35×10^6 [S/m] at 20 ^{o}C, the electrical conductivity of the aluminum casting can vary between 15×10^6 and 25×10^6 depending on the other metals used in the alloy [10-14]. The electrical conductivity and mechanical properties of the aluminum alloy can be greatly changed compared to the materials added even in very small quantities. The IACS value for pure aluminum is 61 percent. 100% IACS (The International Annealed Copper Standard) is equivalent to a conductivity of 58.108 megasiemens per meter (MS/m) at 20 °C [16-20].

The same rule as the first rule described above must be applied separately for each wire. In this case, the current distributions on the terminal and therefore the temperature distributions should be balanced. Therefore, at least half of the conductor diameter must be left between the conductors. In this case, it is also ensured that the casting is in full contact with the wires. Also, assuming that the conductors are divided into two groups, at least two conductor diameters are required between the groups. The width of the terminal surface must be at least 2.5 times the diameter of one wire.

CONCLUSION

The main goal of this study is development of design criteria of high voltage expansion connectors depending on current distribution and temperature. Expansion connectors are used to connect aluminum pipe bases used in high current transport. There are basic rules when selecting a conductor or busbar to carry currents: continuous nominal current transport, long-term overcurrent (120% of nominal current for 2-3 hours per day), short-term (1-3 seconds) short-circuit current flow and voltage drop limits not exceeded. When the overcurrent flow exceeds the determined periods, the thermal damage and the mechanical stress problems are caused. Temperatures measured at different points of a current carrying conductor (busbar) or connector also provide accurate information about the regularity of current distribution. In this study, the importance of sizing the connector connection surface has emerged, depending on the wire diameter and the type of wire used. Especially the number of conductors in the connector, the current to be carried, and the voltage level are the most important factors in the connector design. As a result of the tests and designs made, it turns out that the most prudent factor in practice is the number of conductors. In order to minimize the mechanical and thermal effects of the short-circuit current; the number of conductors must be minimized. The results obtained from the experiments reveal the positive effects of the proposed design criteria.

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REFERENCES

[1] ANSI/NEMA CC 1-2009, Electric Power Connection for Substations, America National Standard, May 2009.

[2] J. Hernández-Guiteras, J.-R. Riba, and L. Romeral, "Improved design of an extra-high-voltage expansion substation connector through magnetic field analysis", Simulation Modelling Practice and Theory 43, 2014, pp. 96-105.

[3] F. Capelli, J.-R. Riba, and J. Perez, "Three Dimensional Finite Element Analysis of the short time and peak withstand current test in substation connectors," Energies 2016, 9, 418.

[4] J. Hernández-Guiteras. J.-R. Riba, and L. Romeral, "Redesign process of a 765 kVRMS AC Substation Connector by Means of 3D-FEM Simulations," Simulation Modelling Practice and Theory vol. 42, March 2014, pp. 1-11

[5] F. Remouit, P. Ruiz-Minguela, and J. Engström, "Review of Electrical Connectors for Underwater Applications," IEEE Journal of Oceanic Engineering, vol. PP, issue. 99, 22 September 2017, pp. 1-11.

[6] M. Braunovic, "Effect of connection design on the contact resistance of High Power Overlapping Bolted Joints," IEEE Transactions on Components and Packaging Technologies, vol. 25, issue: 4, Dec 2002, pp. 642-650.

[7] M. Braunovic, "Power connections," in Electrical Contacts, P. Slade and M. Dekker Eds. Boston MA: IIT 1999, p. 155.

[8] R.L. Jackson, "Significance of surface preparation for bolted aluminum joints," Proc. Inst. Elec. Eng., vol. 128, no. 2, p. 45, March 1981.

[9] J.-R. Riba, A. Garcia, and X. Alabern, "Electric field effects of bundle and stranded conductors in overhead power lines," Comput. Appl. Eng. Educ. 19-1 (2011), pp. 107–114

[10] J.J.-A. Wang, J.K. Chan, and J.A. Graziano, "The lifetime estimate for ACSR single-stage splice connector operating at higher temperatures," IEEE Trans. Power Deliv. 26-3, 2011, pp. 1317–1325.

[11] F. Capelli, "Development of High-capacity substations connectors compatiple with HTLS Technology," Universitat Politecnica de Catalunya Barcelona, Doctor of Phisolophy Thesis, December 2016, p. 152.

[12] L. Lam, and R. Morin, "Specification, performance, testing and qualification of extra-heavy-duty connectors for high-voltage applications," IEEE Trans. Power Deliv. 12-2, 1997, pp. 687–693.

[13] Z.M. Al-Hamouz, "Corona power loss, electric field, and current density profiles in bundled horizontal and vertical bipolar conductors," IEEE Trans.Indust. Appl. 38-5, 2002, pp. 1182–1190.

[14] IEEE Std 4-1995, IEEE Standard Techniques for High-Voltage Testing, Power Systems Instrumentation and Measurements Committee of the IEEE Power Engineering Society, August 1995

[15] http://www.aluminum.org/sites/ default /files/aecd13.pdf, Chapter 13, "Bus conductor design and applications," pp.13.1–13.70.

[16] V. T. Morgan, “The Current Distribution, Resistance and Internal Inductance of Linear Power System Conductors-A Review of Explicit Equations,” IEEE Transactions on Power Delivery, vol. 28, issue: 3, July 2013, pp.1252-1262.

[17] M. Prager, D.L. Pemberton, A.G. Craig, and N.A. Bleshman, “Thermal considerations for outdoor bus conductor design,” IEEE Transactions on Power Apparatus and Systems, vol. 95, issue: 4, July 1976, pp. 1361-1368.

[18] S.W. Melsom, and H.C. Booth, “The current-carrying capacity of solid bare copper and aluminium conductors,” Journal of the Institution of Electrical Engineers, vol. 62, issue: 335, November 1924, pp. 909-915.

[19] S. Valarmathi, and S. Thirumuruga Veerakumar “Analysis of Temperature Rise and Comparison of Materials of Bus Bar used in the MV Panel Board,” Int. Journal of Computer Applications, National Conference on Information Processing and Remote Comput., NCIPRC 2015, pp. 24-27.

[20] R.T. Coyenbeer, W.Z. Black, and R.A. Bush, “Steady-State And Transient Ampacity Of Bus Bar,” IEEE Transaction On Power Delivery, vol. 9 no.4, October 1994.