by Y. Ohki

Development of XLPE-Insulated Cable for High-Voltage dc Submarine Transmission Line (1)

To strengthen electric-power networks, their linkage over broad areas is desirable. Japan is a long, archipelagic country consisting of four major islands, namely Hokkaido, Honshu, Shikoku, and Kyushu, from the northeast to the southwest. Power networks in the four islands are connected with each other, either under water or on land. Among these connecting power lines, those between Honshu and Shikoku and between Honshu and Hokkaido are dc submarine lines; there is also an on-land ac line between Honshu and Shikoku carried on a series of bridges connecting the two islands.

In August 2012 Electric Power Development Co. Ltd. (EPDC), Tokyo, Japan's largest wholesale supplier of electric power, added XLPE-insulated dc submarine cable to the existing Honshu-Hokkaido dc submarine link to strengthen the security of this important power linkage. The cable line was put into operation in December 2012 as the world's highest-voltage extruded dc cable in service and the world's first dc extruded cable for a line commutated converter system including polarity reversal operation.

An account of the cable will appear in this column, spread over two consecutive issues. Fundamental results obtained from a series of interuniversity joint research projects, undertaken to understand the basic properties of the insulating material, are described in this issue. In the following issue, details of the cable and the dc linkage line will be presented.

The cable, manufactured by J-Power Systems Corporation (JPS), Tokyo, is insulated with cross-linked polyethylene (XLPE). However, the mother resin is not a regular low-density polyethylene (LDPE), but a so-called polymer nanocomposite, i.e., LDPE to which very tiny particles of a certain inorganic oxide were added.

Research aimed at developing useful nanocomposites commenced more than 10 years ago. Some of the early research activities were reported in this column in 2005 [1]. After JPS staff discovered that some nanocomposites containing very tiny inorganic particles exhibit good insulating properties relevant to cable insulation, they wanted to confirm their findings. For this purpose, they organized an interuniversity research consortium in which five professors from four universities participated, namely Professors Toshikatsu Tanaka of Waseda University at the Kita-kyushu Campus, Masayuki Nagao of Toyohashi University

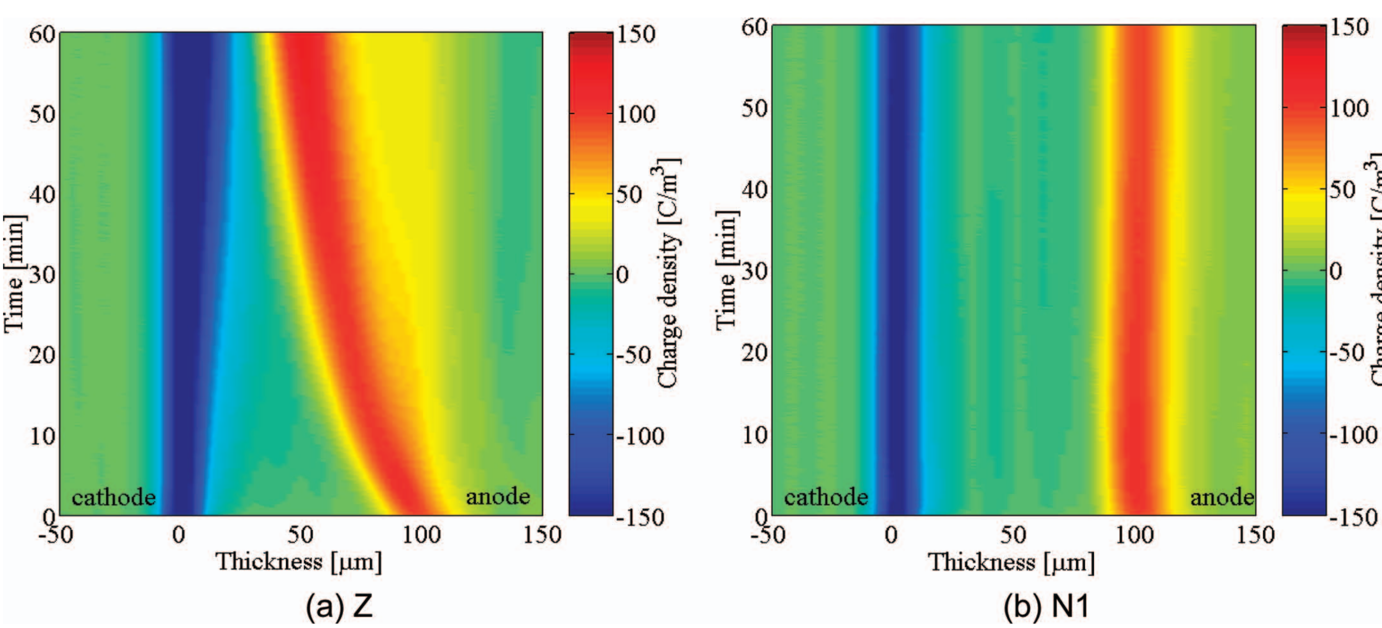

Figure 1. Space-charge distributions observed during the application of a dc field of 150 kV/mm at room temperature. Z: LDPE, N1: LDPE/MgO nanocomposite [2].

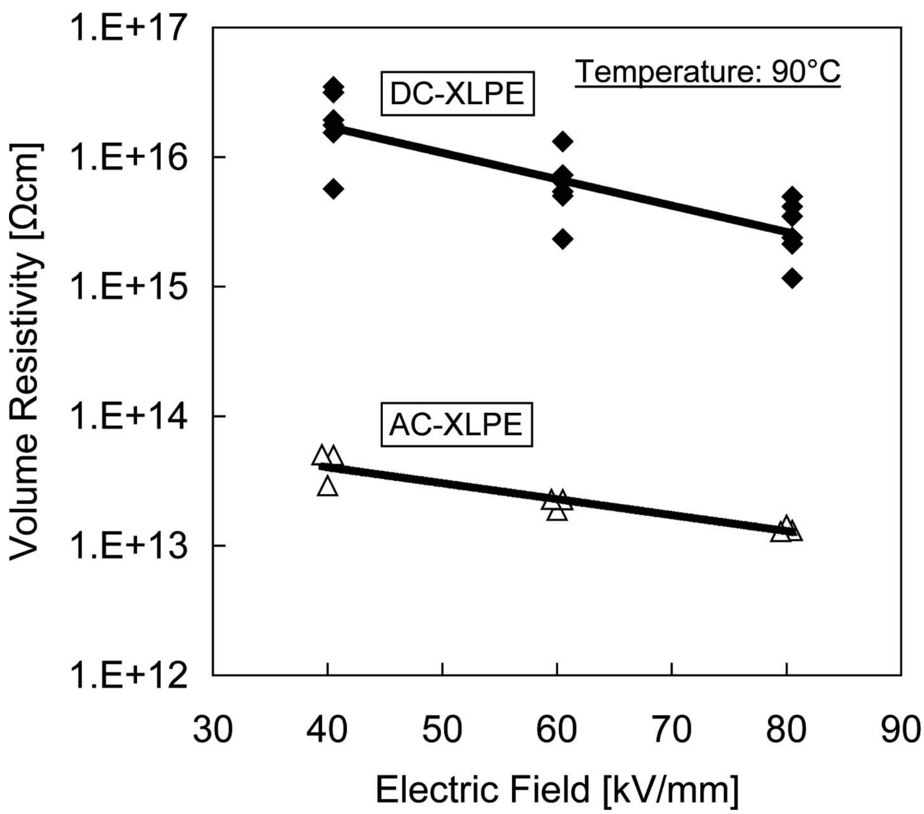

Figure 2. Dependence of volume resistivity on the average electric field strength.

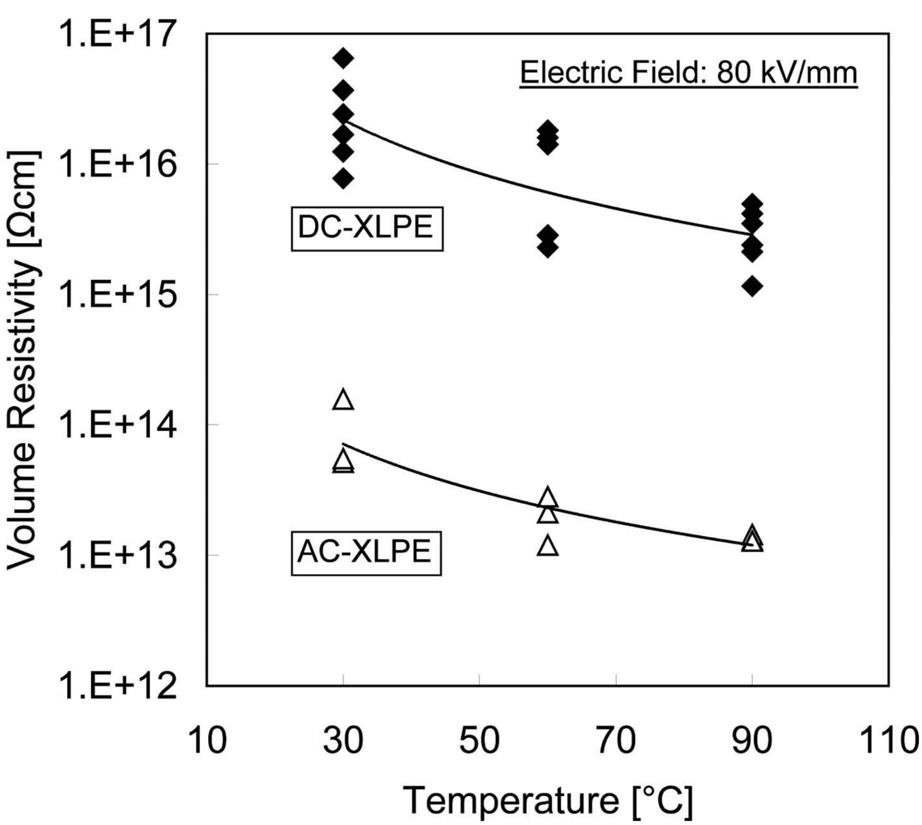

Figure 3. Temperature dependence of the volume resistivity.

of Engineering, Yasuhiro Tanaka of Tokyo City University, Kazuyuki Tohyama of Numazu National College of Technology, and Yoshimichi Ohki of Waseda University at the Tokyo Campus (the author of this article). Although much research was done by this consortium, mainly on the composite of LDPE with nanosized MgO fillers, various properties of the composite of XLPE with several nanosized inorganic fillers were examined by JPS.

Figure 1, a typical example of the data obtained in the consortium research, shows clearly that the progress of positive space charge from the anode to the cathode, observed in the pure LDPE sheet when a dc electric field of 150 kV/mm was applied at room temperature [2], was not seen in the LDPE nanocomposite sheet. The consortium found that the composite of LDPE with nanosized MgO fillers possessed good basic electrical properties, e.g., dielectric breakdown strength, insulation resistance, and partial discharge resistance.

Concurrently, JPS researchers were doing experiments on XLPE nanocomposites, incorporating additives expected to improve the performance of XLPE as a cable insulation material. They were interested in comparing an XLPE nanocomposite sheet, developed for dc transmission cables, with a regular XLPE sheet without any fillers developed for ac transmission cables, particularly with respect to various properties especially important for cable insulation. In this article the former is called DC-XLPE, while the latter is called AC-XLPE. Figure 2 compares the dependence of the volume resistivities on average electric field strength, measured at 90°C, and Figure 3 compares the dependence of the volume resistivities on temperature, measured at an electric field strength of 80 kV/mm. Clearly the volume resistivity of DC-XLPE is about 100 times greater than that of AC-XLPE, over the investigated ranges of electric field strength and temperature.

Figure 4 shows the relationship between the average applied dc electric stress (E_{mean}) and the time to breakdown (t_B) for an AC-XLPE and a DC-XLPE sheet measured at 90°C. The AC-XLPE sheet (no nanofillers) shows much shorter values of t_B than does the DC-XLPE sheet

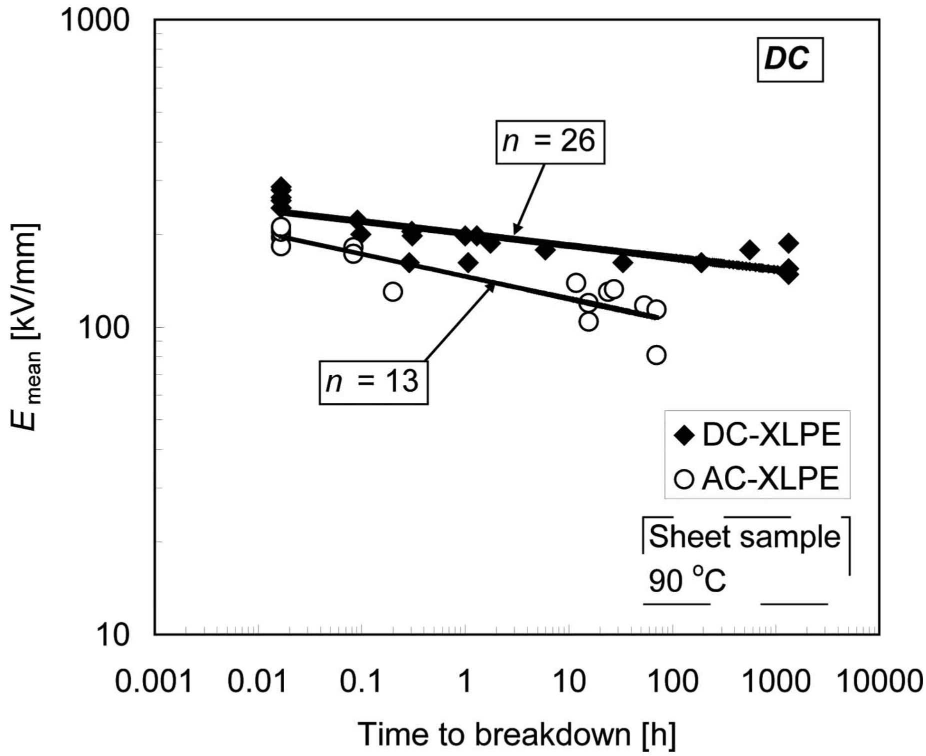

Figure 4. Relationship between average applied electric field E_{mean} and time to breakdown for DC-XLPE and AC-XLPE sheet samples at 90°C.

(with nanofillers). Expressing E_{mean} as a function of t_B in the form $E_{\mathrm{mean}} \propto t_B^{-(1/n)}$, n is about 26 for DC-XLPE and about 13 for AC-XLPE. Because E_{mean} at the instant of breakdown is the dielectric breakdown strength (E_B), a larger value of n means that, for a given E_B, t_B is larger. It follows that, at the same E_B, DC-XLPE should be usable for a much longer period than AC-XLPE.

Many other research results were obtained by the consortium and by JPS. They all consistently indicated that the XLPE nanocomposite is a good material for high-voltage dc insulation. Consequently XLPE nanocomposite was adopted in the Honshu-Hokkaido dc high-voltage linkage. Details of the cable and the linkage line will be presented in the next issue.

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References

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[2] Y. Ohki, K. Ishimoto, E. Kanegae, T. Tanaka, Y. Sekiguchi, Y. Murata, and C. C. Reddy, “Suppression of packet-like space charge formation in LDPE by the addition of magnesia nanofillers,” in IEEE Proceedings of the International Conference on Properties and Applications of Dielectric Materials (ICPADM), Harbin, China, 2009, pp. 9–14.