Technical Description

LOW FREQUENCY C and Tan δ METER DAC-LFM-3

Overview of Model DAC-LFM-3

Model DAC-LFM-3 is designed to measure tan δ and capacitance by making use of a built-in very-low frequency power source.

This instrument uses a very-low frequency of 0.1 Hz or 0.01 Hz to measure tan δ and capacitance.

Measurement of tan δ and capacitance using a very-low frequency is realized by full digital processing with a 32-bit MPU.

Values of tan δ and capacitance serve as important indices for the determination of insulation deterioration of power cables, etc. Traditionally, commercial frequency has generally been used to measure tan δ and capacitance. This approach, however, requires large equipment for the power source, which is high in investment and running costs, along with time-consuming operation. For this reason, the determination of insulation deterioration turned to DC withstand-voltage test and other convenient methods of measurement instead of the commercial frequency approach.

The impedance of test sample becomes extremely large at very low frequencies; this means that measurement requires only a power source of very small capacity, one-several thousandths of capacity of commercial frequency approach.

Model DAC-LFM-3, although compact in size, can be used to measure tan δ and capacitance of test samples that are very large in capacitance, such as power cables.

This instrument can also be applied to distributed parameter circuits, such as ultra long power cables, to yield very accurate results of measurement.

A distributed parameter circuit contains complex distributed parameters, which make the impedance measurement difficult to analyze.

Although these difficulties cannot be resolved with the conventional commercial frequency approach, measurement using a very-low frequency adopted by Model DAC-LFM-3 can eliminate complex parameters, thereby enabling accurate measurement of tan δ and capacitance.

This instrument is compact, lightweight, and suitable for hand carrying in the field.

Measurement operations are very simple; just connect the measuring cable to a given test sample.

A USB interface, equipped as standard, allows data acquisitions by means of a PC.

A single unit of Model DAC-LFM-3 suffices to function as a tool of insulation diagnosis of power cables.

Specific Applications of Model DAC-LFM-3

Drying process control for oil-filled or mineral insulated cable

Oil-filled or mineral insulated cables are used for DC submarine transmission lines.

These cables are impregnated with insulating oil or resin. Moisture content remaining in insulating materials prior to the impregnation of insulating oil greatly affects cable quality. Therefore, moisture content control is important in a manufacturing process preceding the impregnation of insulating oil.

Previously, empirical control of moisture content has been normal practice. This instrument provides accurate numerical control of moisture content during a drying process of oil-filled cable manufacturing. In general, cables prior to the impregnation of insulating oil show higher values of tan δ while moisture remains, and show lower values of tan δ as the cables become increasingly dried.

The values of tan δ become unmistakable at lower frequencies, thereby values of tan δ measured at very-low frequencies serve as an indicator of moisture content. In this way, precise detection of values of tan δ can lead to quantitative control of moisture content. Consequently, it is possible to proceed to the next process after finishing the previous process adequately, and as a result, production efficiency can be improved considerably.

This instrument can provide great help to labor saving and quality assurance in the manufacturing process of oil-filled cable or the like.

Failure Point Identification of Optical Fiber Submarine Cables

Optical fiber submarine cables are used also as a power transmission line for repeaters.

When a cable is damaged (broken), measurement of its capacitance is essential for failure point identification.

Because an optical fiber submarine cable is stretched a long distance, its capacitance is very large. Therefore, it is difficult to accurately measure its capacitance and tan δ, which are affected by cable conductor resistances (serial resistances) and leakage resistances of cable insulating material (parallel resistance).

Under these circumstances, for example, Model DAC-LFM-3 can measure capacitance of up to 5,000 μF when a frequency of 0.01 Hz is used.

Being free from the effects of serial resistances and parallel resistances result in high-precision measurement of capacitance, making this instrument suitable for accurate failure-point identification of broken submarine cables.

Insulation Diagnosis of Commercial Frequency Power Cables

Commercial frequency approach for the measurement of power cable requires large equipment for the power source, which is high in investment cost and involves operation risks, and thus it is extremely difficult to perform measurement in the field.

Because this instrument uses very low frequencies for measurement, the cost of equipment for power source is one-several thousandths of that of the commercial frequency approach.

Failures associated with insulation deterioration of power cables are indicated by small changes in parallel resistances relative to cable capacitances. In a usual withstand voltage test, combined currents of leakage currents by parallel resistances and charging currents of cable are measured, resulting in remarkably inferior detection sensitivity

Insulation diagnosis of power cables requires accurate measurement of the leakage current due to parallel resistances and the loss currents due to defects of insulating materials.

Model DAC-LFM-3 displays the ratio (tan δ) of the leakage current and the loss current relative to the cable charging current.

This value of tan δ can be used as an index that represents the status of insulation deterioration, irrespective of the magnitude of cable capacitance.

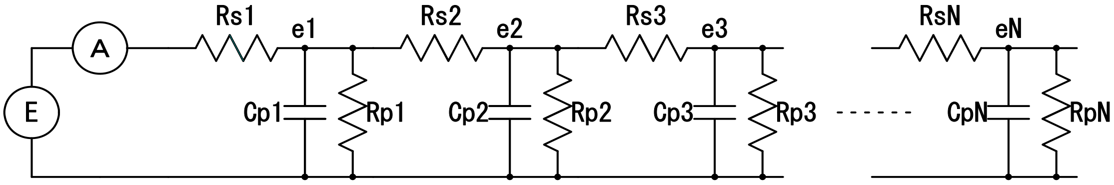
The value of tan δ, which can be measured obviously at very low frequencies, can detect small changes in the degree of insulation deterioration.

Technical Basics: Capacitance of Ultra Long Cable

Long cables, such as DC transmission cables, are very large in capacitance, and can be represented by a distributed parameter circuit containing serial resistances and parallel resistances.

To measure the capacitance and tan δ of such cables, characteristics of an equivalent circuit must be considered carefully. Figure 1 illustrates the equivalent circuit for a long cable, such as a DC transmission cable, when an AC voltage is applied.

Figure 1 Equivalent Circuit When A.C. Voltage is Applied to Long Cable



Here, Rs1 through RsN are sheath resistances and conductor resistances of the cable, Rp1 through RpN are leakage resistances of insulating material of the cable, and Cp1 through CpN are distributed capacitances of the cable.

In the AC circuit (commercial frequency), it can be approximated as a distributed parameter circuit. For a given voltage E, the following relation, E > e1 > e2 > e3 …… > eN, holds, and therefore a uniform voltage is not applied to Cp1 through CpN.

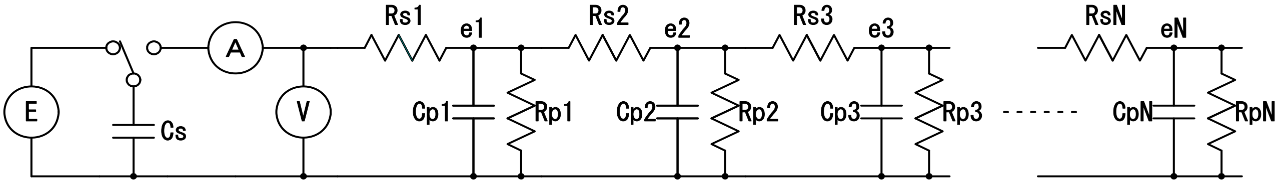
If the circuit were a lumped parameter circuit and parallel resistances could be ignored, the current that flows through the ammeter would be given by the following equation:

$$i = j\omega Cx * E \quad \text{.......} \quad (1)$$

Then, the equation (1) could give the capacitance Cx. Actually, however, because of the presence of parallel resistances and the relation of E > e1 > e2 > e3 …… > eN, the true value of Cx (Cp1 + Cp2 + Cp3 + …… + CpN) cannot be determined.

Another method is given below to determine the capacitance Cx by applying a charge Qs = E・Cs to a long cable.

Figure 2 Equivalent Circuit When Known Charge is Applied to Long Cable



As shown in Figure 2, charge a standard capacitor Cs with E. Then, turn the switch to the cable side. The charge accumulated in the Cs is then propagated to the cable; when the current flowing through the ammeter becomes zero, the influence of serial resistance can be ignored and the voltage of the same amplitude V (V = e1 = e2 = e3 …… = eN) is applied to distributed capacitances.

Suppose that the combined capacitance of the circuit Ct is given by Ct = Cs + Cp1 + Cp2 + Cp3 …… + CpN; then, the following equation is obtained.

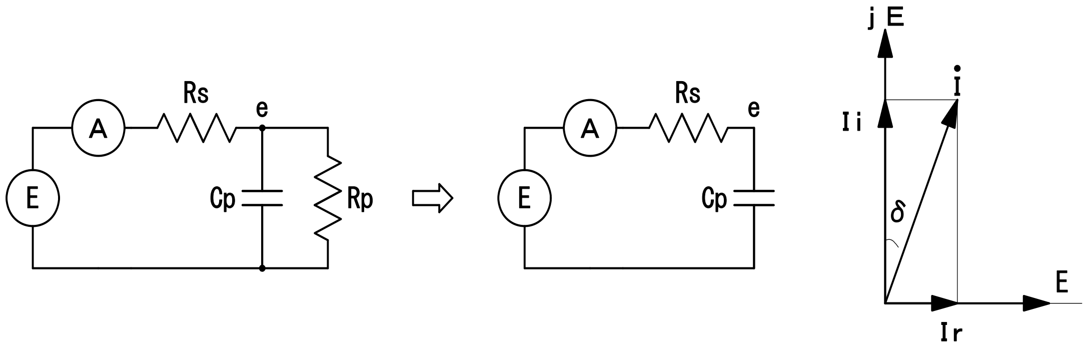
$$Q = Cs \cdot E = V \cdot Ct = V \cdot (Cs + Cp1 + Cp2 + Cp3 \ldots\ldots + CpN) \quad \text{.......} \quad (2)$$

Finally, Cx (Cp1 + Cp2 + Cp3 + …… + CpN) can be determined by equation (2).

Actually, however, Q is not equal to V・Ct, because electric charges are lost by the parallel resistances Rp1 through RpN, and therefore V gradually decreases with time. Consequently, accurate determination of the capacitance by this method is not possible.

The method adopted by Model DAC-LFM-3, which uses a very-low frequency to measure tan δ value, can be applied to accurate determination of tan δ and capacitance of distributed parameter circuits.

Figure 3


Equivalent circuit when very-low frequency voltage is applied

Equivalent circuit when ZRp >> ZCp is assumed

Vector diagram

Figure 3 shows an equivalent circuit when a very-low frequency voltage is applied to a distributed parameter circuit. With a very-low frequency power source, the equivalent circuit can be approximated as a lumped parameter circuit; in this case, a simple serial-parallel circuit consisting of Rs, Cp, and Rp due to capacitance is not distributed but concentrated. Rs represents the cable conductor resistance and the sheath resistance; Cp represents the cable capacitance; and Rp represents the cable insulation resistance parallel to the cable capacitance.

Because the insulation resistance Rp consumes part of the charge accumulated in the Cp (energy loss), the method shown in Figure 2 will result in a large measurement error.

When AC low frequency constant voltage is applied to a cable, the resultant current consists of an active current and a reactive current, and that ratio is expressed as the tangent of the phase.

If the capacitance Cp and the serial resistance Rs of a cable are very large, and the parallel resistance Rp (insulation resistance) is also large, as those of ultra long submarine cables are, the cable can be assumed to be normal, having a high insulation resistance, and ZRp is very large compared with ZCp, then Rp can be almost neglected, and finally the equivalent circuit can be simplified to a simple serial equivalent circuit consisting of Rs and Cp alone.

A similar equivalent circuit can be assumed for a failure mode when a cable is broken halfway but the parallel resistance is still large.

When a low frequency AC voltage E is applied to such an equivalent circuit, the resulting current I in the circuit lags by the phase delay angle δ behind jE. Model DAC-LFM-3 displays the phase delay angle δ as tan δ.

The true capacitance Cp to be determined can be calculated from the measured capacitance C and the tan δ value according to the established relation of $C = 1/(1 - (\tan \delta)^2)$.

In this way, Model DAC-LFM-3 can accurately measure the capacitance of ultra long cables independently of cable serial resistances and parallel resistances, even if they are present.