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EXPERIMENTAL INVESTIGATION OF LEAKAGE CURRENT IN POWER CABLES UNDER DIFFERENT OPERATING CONDITIONS

By

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ABSTRACT:

This paper reports an expermintal investigation into the effect of different factors on the leakage current in power cables. The leakage current of different cables was studied using installed cables under actual operating conditions and also cable samples in HV-laboratory under well-controlled conditions.

The results obtained showed that, the leakage current in any power cable depends on many factors, including the value and type of the applied voltage, time of voltage application, cable type and construction, and the type of the surrounding soil and its resistivity. These results showed also that leakage current in power cables can be considered as a predictor of the cable failure because it is a good indicator of the cable deterioration.

1. INTRODUCTION:

Power cable represents a main part of any distribution and transmitting scheme of any electrical system. It is well known that the cost of a power cable is more than that of an overhead line for the same length and transmitted power. Power cable replaces the overhead line especially in urban areas for reasons of safty, in or around plants and substations or crossing a wide bodies of water, which for various reasons would not permit of overhead crossing.

The kind of insulation and type of power cable used depend on the voltage and service requirements. Insulating materials for cables used in the transmission and distribution of electrical power are in principle four different types, namely; solid-type, oil-filled, gas-pressure and plastic insulation. Public demand and improved technology subsequently have made underground distribution a common supply method. Polythylene rubber or other rubber-like is practically the universal choice.

Direct burial is the least expensive of cable installation, now being used in underground residential distribution schemes. Care must be taken in trenching to the proper depth, installing of the cable and protecting the cable from damage by digging or other means with a concrete slab or corrugated non-metalic sheathing.

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Power cables used for A.C. transmission can also be used for D.C. Owing to better utilization of insulation and absence of capacitive currents they are normally capable of transmitting more D.C.power than A.C.

Numerous tests are performed on any power cable after manufacturing and during opertion, but only measurement of the leakage current under high voltage is the most reiable guide to the quality and state of the cable. Leakage current in power cables can be considered as a good detector of the deterioration of the cable especially if the deterioration of the cable is progressed to a point where the cable failure is imminent.

Leakage current in a power cable under applied voltage flows in a special path through the insulation, sheath and armouring to the ground. Therefore, the leakage current of power cables depends on many factors associated with all the components of the whole path. In addition, there are other factors affecting the leakage current in power cables. These factors include the applied voltage, time of voltage application, cable type and soil resistivity. These factors were carefully investigated experimentally under A.C. voltage and D.C. voltage of both polarities.

2. EXPERIMENTAL RESULTS AND DISCUSSIONS:

2.1 General:

To study the effect of different operating comditions on leakage current of power cables, numerous experimental tests were carried out under both actual operating conditions and well-controlled conditions in high-voltage laboratory on different cable types. Measurements in operating field were taken by using a cable Testing and Measuring Vehicle of type RFT. This contains all equipment necessary for all electrical testing of any HV-cable and for rapid locating of all kinds of faults in the cable. It contains a megger, a measuring bridge, high-voltage generating circuits and their necessary instruments such as a microammeter and HV-electrostatic voltmeter, both D.C. and A.C. voltages. In both cases, leakage currents were measured by means of a microammeter having full measuring scale of 100 μA, which can be multiplied to indicate a current of 100 mA.

The cables under test were chosen to represent the main types of cables used in Egypt in both transmission and distribution schemes of electrical power. These types are all of solid types including impregnated-paper, oil-filled and polyethylene cables. The cable samples were prepared for testing in HV-laboratory each having 1 m legth, while in field the cable length was at least 30 m.

The leakage current in a power cable under applied voltage flows in a special path through the insulation, sheath and armouring to the ground. Therefore it depends on many factors associated with all these components of the whole path. In addition, there are other factors affecting leakage current in power cables. These factors include applied voltage, time of voltage application, cable type and soil resistivity. These factors were carefully investigated in the present work, while some other factors were examined and discussed in a previous work for the same author.

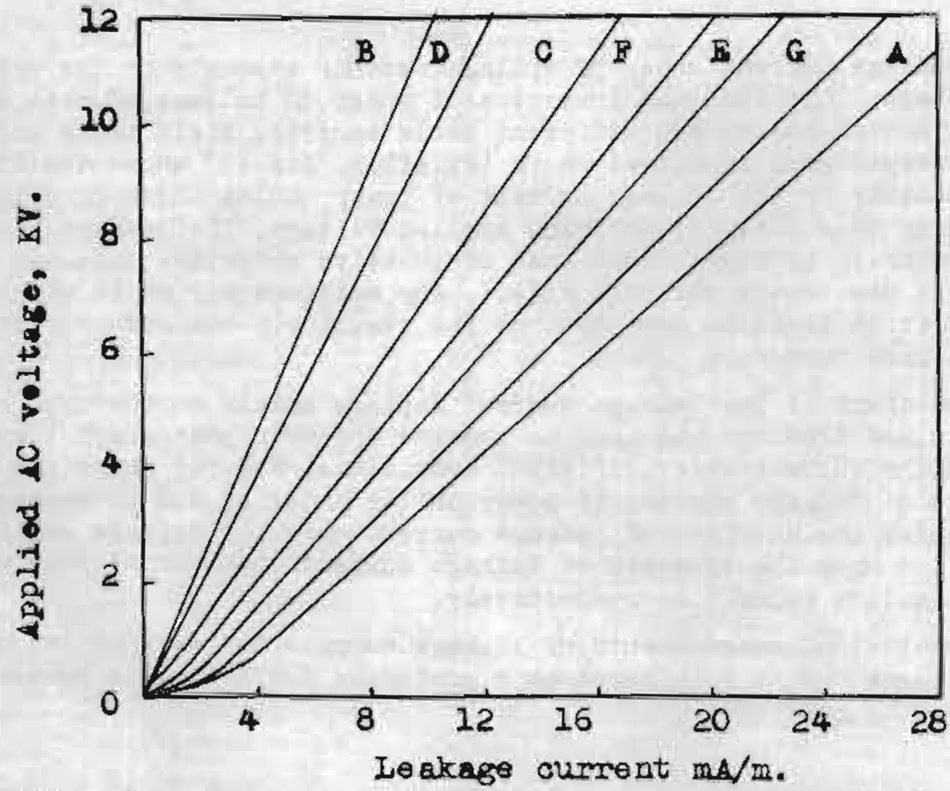
Each value of the leakage current shown in the given figures represents the mean current per meter length. The mean value was calculated from 5 successive measurements after sufficient intervals to avoid any recharging of the cable under test. The standard deviation of the results was found to be dependent on both cable type and applied voltage. It was found to be in the order of up to 15%.

The given results were obtained from tests carried out on cable samples in the HV-laboratory by increasing the applied voltage smoothly at a constant rate of 1 kV/sec. The same rate was used in testing power cables under actual operating conditions. In this case, the obtained results were very close to those obtained from tests in the same laboratory.

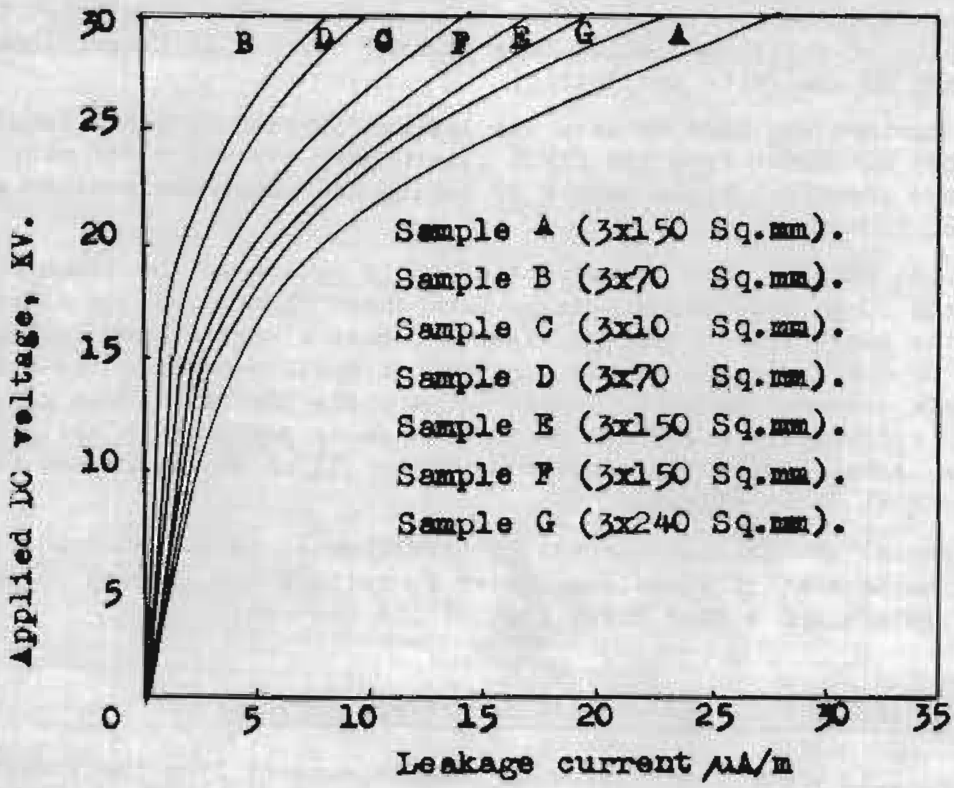
2.2 Effect of Applied Voltage on Leakage Current:

The leakage current was measured between core and core and between sheath and the three cores connected together. Voltage was applied and readings of leakage current were taken after dying away of any transient current. At each applied voltage, the measurement of leakage current was repeated successively 5 times after sufficient intervals and discharging of the cable. Tha leakage current was taken as the mean value of the 5 successive measurements. All tests were conducted under normal conditions, e.g. 20°C and 760 mm Hg barometric pressure.

Figure(1) shows the dependence of the leakage current on the applied A.C. voltage for different cable samples. These cable samples were selected to cover all types of cables used in Egypt in transmission and distribution of electrical power. It is clearly seen that, the leakage current of power cables depends not only on the applied voltage but also on the dimensions, construction and insulation of the cable. As a comparative example, at applied voltage of 10 kV(r.m.s.) sample A had leakage current of 24.4 mA/m, while sample B gave only 8 mA/m. This means that, the current of the first sample is 3 times that of the second sample. Thus, the leakage current depends strongly on the diameter of the core and on the overall diameter of the cable. It depends also on the type of cable insulation which can be clearly seen in Figure (1), samples A and F. At the same mentioned voltage, the leakage current of sample F (XLP - 300) was 17 mA/m. Sample A has impregnated paper as insulation and sample F has polythelene. The variation in the leakage current of these two types under A.C. voltage is produced by the variation of the electrostatic capacitance of these cables. The value of this capacitance between two cores per unit length depends on the relative permittivity of the insulation and dimension of the cable. In general, the increase of the leakage current with the applied voltage can be explained to be due to the capacitance and the dissipation factor of cable insulation. The type of applied voltage affects also the leakage current of power cables. To investigate this factor, the cable samples were tested under D.C. voltage of both polarities. Figure (2) shows the variation of leakage current per unit length of power cable with D.C. voltage of positive polarity for different cable types. Under D.C. voltage the leakage current can be explained to be due to conduction and polarization of the cable insulation. As the D.C. voltage is applied to the cable, a comparatively high current will flow. This corresponds to the initial charging current. Rapidly this current falls to a comparatively very low current, namely the true conduction current , which was in all tests, under DC voltage, in the order of some microamperes/meter. It is clearly seen from Fig.(2) that, the leakage current of power cable under DC voltage increases with the increase in applied voltage. As a second example for three samples mentioned before the corresponding leakage current per meter were 7.5, 1.3 and 3.8 μA for the respective samples A, B and F. The variety of these values is produced due to the differing of the cable insulation of the three samples.



Fig(1): The leakage current versus the applied AC voltage for different cable types.



Fig(2): The leakage current versus the applied DC voltage of positive polarity for different power cable types.

The leakage current under DC voltage depends strongly on the polarity of the voltage. This fact was investigated under DC voltage of both polarities using actual cables and different cable samples. Field tests and HV-laboratory tests gave identical characteristics. Fig.(3) shows the effect of voltage polarity on the leakage current of power cables under DC voltage. It is clearly seen that, at the same applied voltage, the leakage current of negative polarity is higher than that of positive polarity. This can be explained to be due to the moisture effect. Any moisture may exist within the cable insulation tends to move towards the negatively-charged core increasing the leakage current.

The waveform of the leakage current depends mainly on the type of applied voltage. An oscilloscope was used to observe and even photograph the waveform of the leakage current under different conditions. Fig.(4) shows the oscilloscope traces of leakage current in power cables under AC and DC voltages. Fig.(4a) shows the waveform of leakage current under AC voltage while Figs. (4b) and (4c) show the waveform of leakage current under DC voltage of positive and negative polarities respectively.

In conclusion, measurements of leakage current in power cables under AC and DC voltages can be considered as a predictor for the cable behaviour under operating conditions.

2.3 Ageing Effect on the Leakage Current:

The leakage current depends strongly on the state of the cable under test. The leakage current of impregnated paper cable withdrawn from service after a long operating period was investigated carefully under operating conditions and in HV-laboratory under well controlled conditions. The increase in the leakage current of cable after long use is mostly attributed to the deterioration of cable insulation. The leakage current is proportional to the power factor of the cable dielectric.

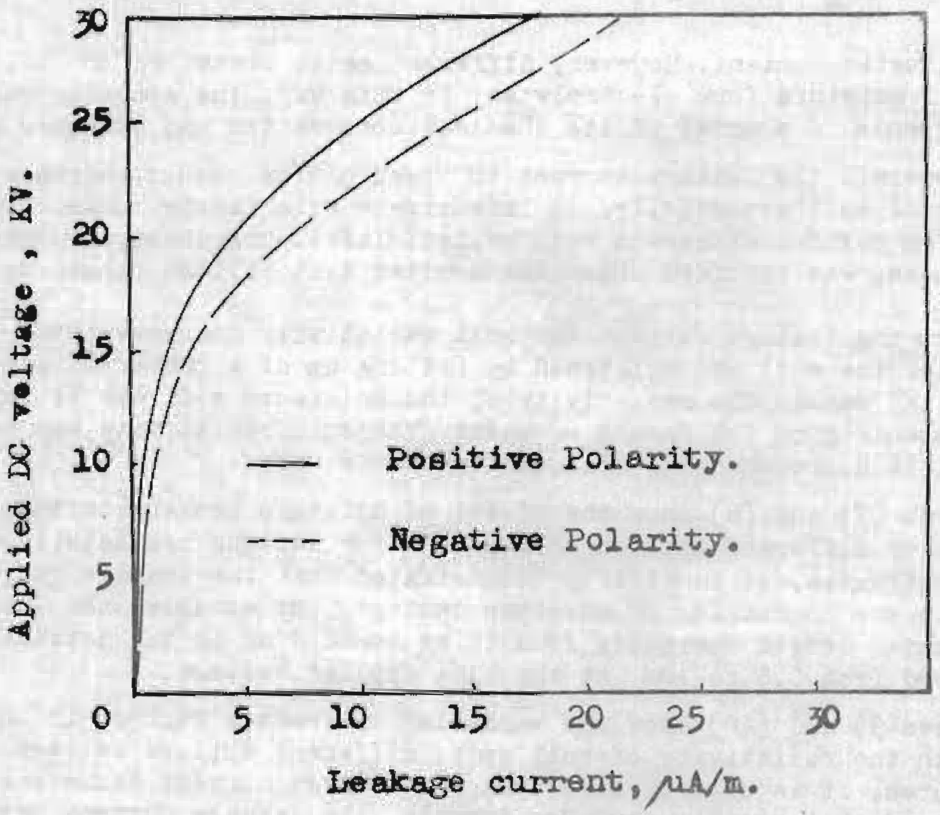
A comparison was made between the leakage current in cable sample C (3x70 sq.mm) withdrawn from the field after heavy operation for many years and in a new identical cable sample D, having the same construction and dimensions.

Figs.(5) and (6) show the effect of cable ageing on the leakage current under AC and DC voltage respectively. From these figures, it is clearly seen that, at the same applied voltage, sample C gave always higher leakage current than that of the new cable sample D. As a comparative example the old cable gave leakage current per meter length 14 mA while the new sample gave 10 mA, both at 10 kV(r.m.s.), Fig.5. Under DC voltage of positive polarity the old cable gave leakage current per meter length of 14 µA while the new cable gave 8 µA/m, both at 30 kV (Fig.6).

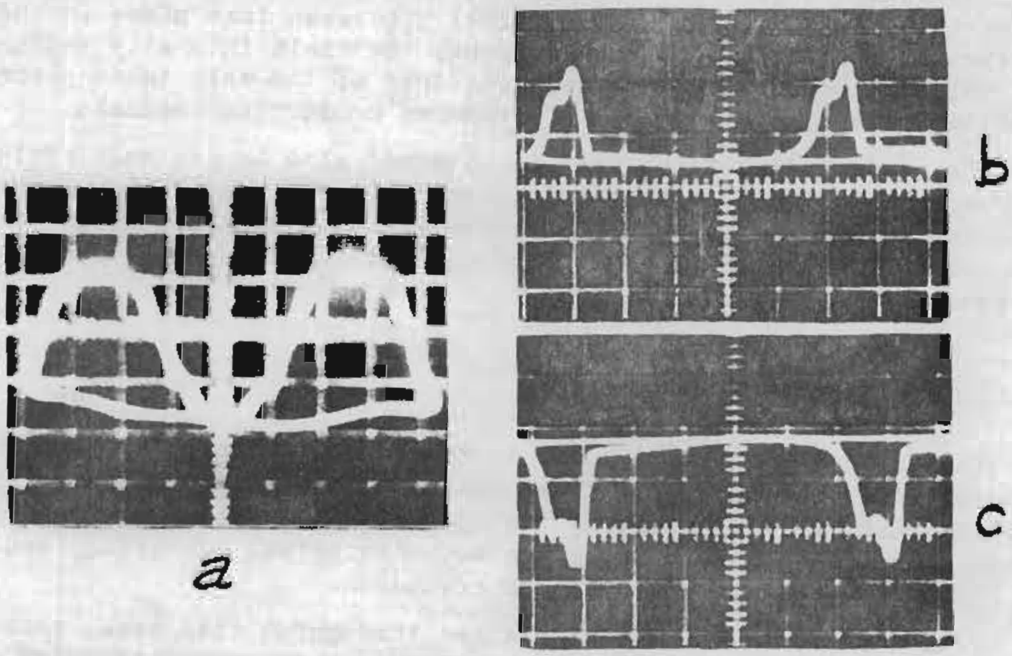
In general the leakage current of deteriorated cable under DC voltage is nearly twice that of a new one. Under AC voltage the leakage current of old cable is one and a half times that of the new cable.

2.4 Effect of the Soil Resistivity on Leakage Current:

The soil in which the outflow of leakage current from the sheath of cable, is complicated and heterogeneous in composition as well as in structure. The main component parts of soil are hard particles of inorganic and organic



Fig(3): The variation of the leakage current with the polarity of the applied DC voltage for core to sheath connections.



Fig(4): Oscilloscope traces of the wave-form of leakage current in power cable under A.C. (Ph.a) and D.C. voltage (Ph(b) + ve and - ve) voltage.

origin and water content. However, different salts contained in soil in the presence of moisture form electrolytes. In this way, the specific resistance of soil depends of course, on its chemical composition and moisture content.

In general, the leakage current in power cables should increase with decreasing of soil resistivity. To investigate this factor, measurements were carried out for different soil resistivities. The leakage current in cable samples, was recorded under the applied test voltage ranged up to 30 kV.

To get the leakage current and soil resistivity characteristic of the power cable, the soil was moistened by filling up of a number of pores in the soil with tap water. The resistivity of the moistened soil can be very much reduced depending on the amount of water. The soil resistivity can be decreased till it approaches the resistivity of the water.

Figures (7) and (8) show the effect of moisture content on the leakage current under different applied voltage and for various resistivity of soil. From these figures, it is clearly demonstrated that the leakage current increases with the increasing of moisture content. For example, the leakage current per meter length increases from 16 mA to 24.4 mA as the moisture content is increased from 0.5 to 10% at the same applied voltage.

Figures(9) and (10) show the variation of leakage current in underground cables with the resistivity of soil under different applied voltage. From these figures, it is clearly seen that the leakage current decreases with the increasing of soil resistivity. For example, the leakage current per meter length decreases from 33.5 μA to 28 μA as the soil resistivity is increased from 10^4 to $7x10^5$ ohms-cm at the same applied DC voltage of 30 kV with negative polarity.

The soil can be affected by the leakage current flowing from the metal to the earth. Complicated physico-chemical processes take place in the soil. With the further increase of leakage current, the field intensity reaches a critical value at which the electrical breakdown of the soil takes place. This breakdown develops in the form of branched conducting channels.

The resistivity of the soil is governed also by its salt content. In other words, the salt content in the soil affects the leakage current in power cables. The leakage current increases as the salt content is raised. High leakage currents may dry their pathes through the soil leading to a local increase in the soil resistivity.

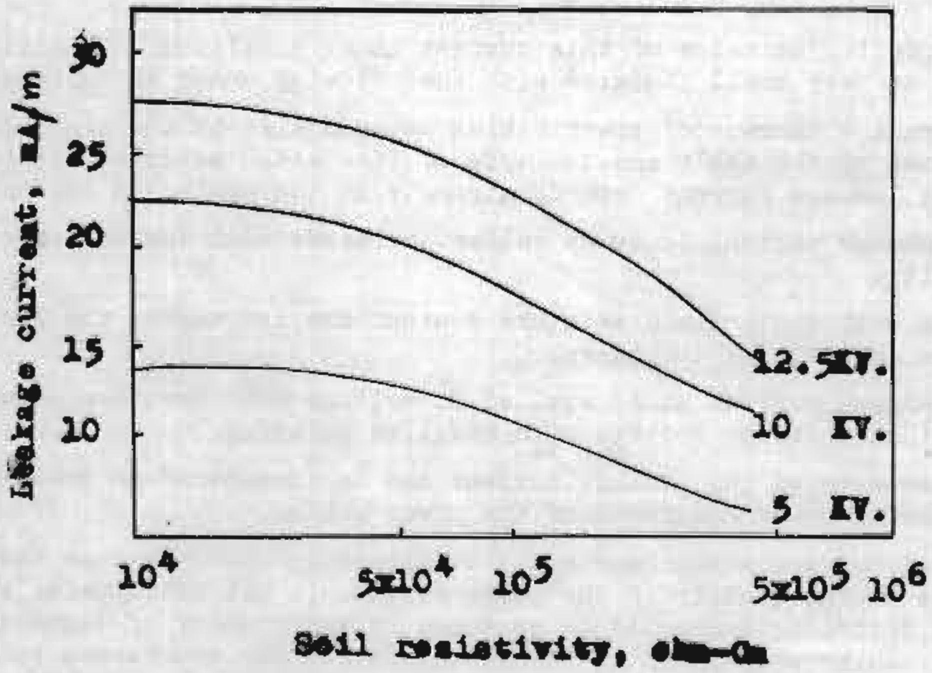
3. CONCLUSIONS:

The present work was planned to study the factors affecting the operation of power cables. Among these factors, the leakage current forms the most important factor affecting the operation and even the life of power cables. The leakage current was tested under actual operating conditions and can be taken as predictor for cable breakdown.

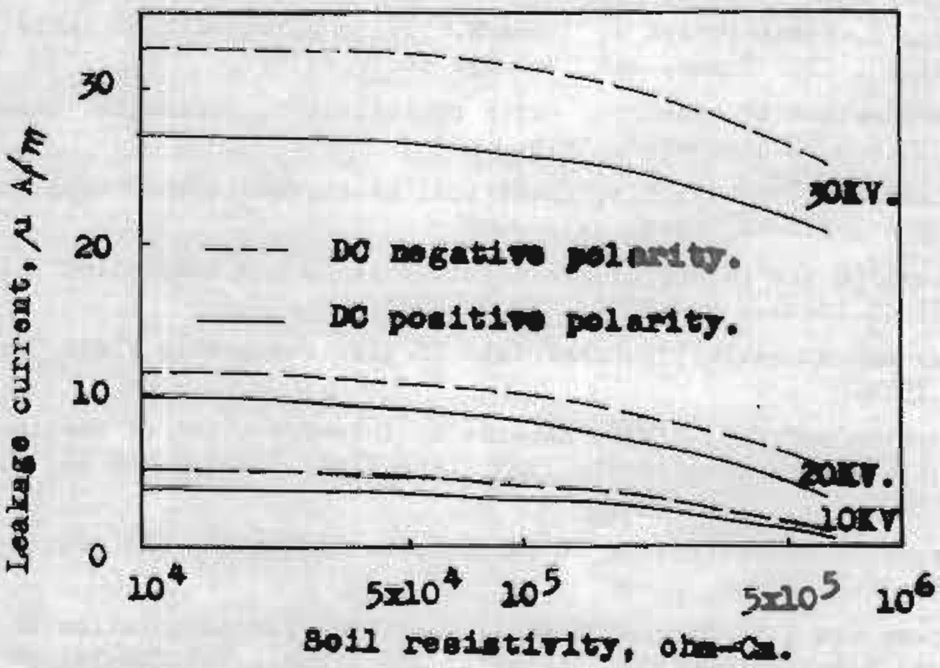
From the previous results obtained throughout this work, which were carried out to investigate the leakage current in power cables under different operating conditions, the following conclusions can be drawn:

1. The value of the leakage current under applied HVDC or HVAC increases with increasing the applied voltage.

2. The time of voltage application has a considerable effect on the leakage current of power cables. At the moment of applied DC voltage application a comparatively very high current will flow and decreases to a small



Fig(9): Variation of leakage-current on under ground cables with the resistivity of earth under different applied AC voltage.



Fig(10): Variation of leakage current in under-ground cables with the resistivity of soil under different applied DC voltage.

conduction current. The value of this current under continuous connection of DC voltage is very small compared with that flowing under AC voltage.

3. The leakage current of power cables depends also on the dimension and construction of the cable and the type of insulation material. It is found that the leakage current depends strongly on the ageing of the cable.

4. The leakage current in power cables increases with the decrease of soil resistivity.

5. As the salt content and moisture content are increased, the leakage current in the cables also increases.

6. The leakage current under applied DC voltage with positive polarity is less than that under DC voltage with negative polarity.

7. Measurements of the leakage current can be considered in practice as the main predictor of breakdown of the power cables.

8. Leakage current measurements can be generally recognized as the most reliable guide to the quality of the power cables. It was anticipated that a sagnificant deterioration could be detected by measurement of leakage current of power cables especially if the deterioration has progressed to a point where the cable failure was imminent.

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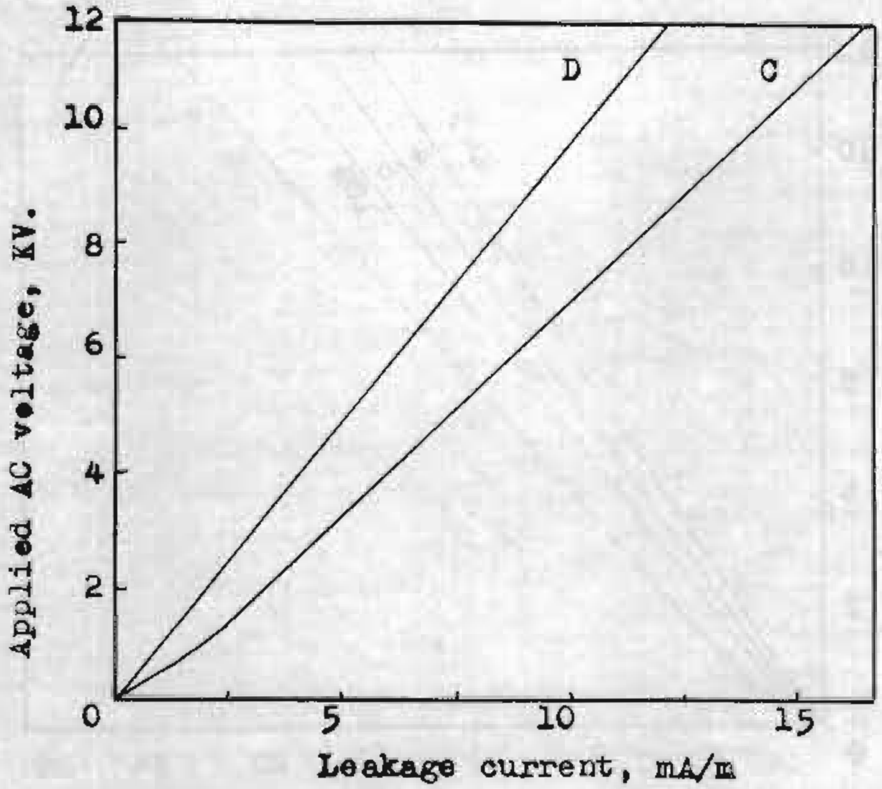
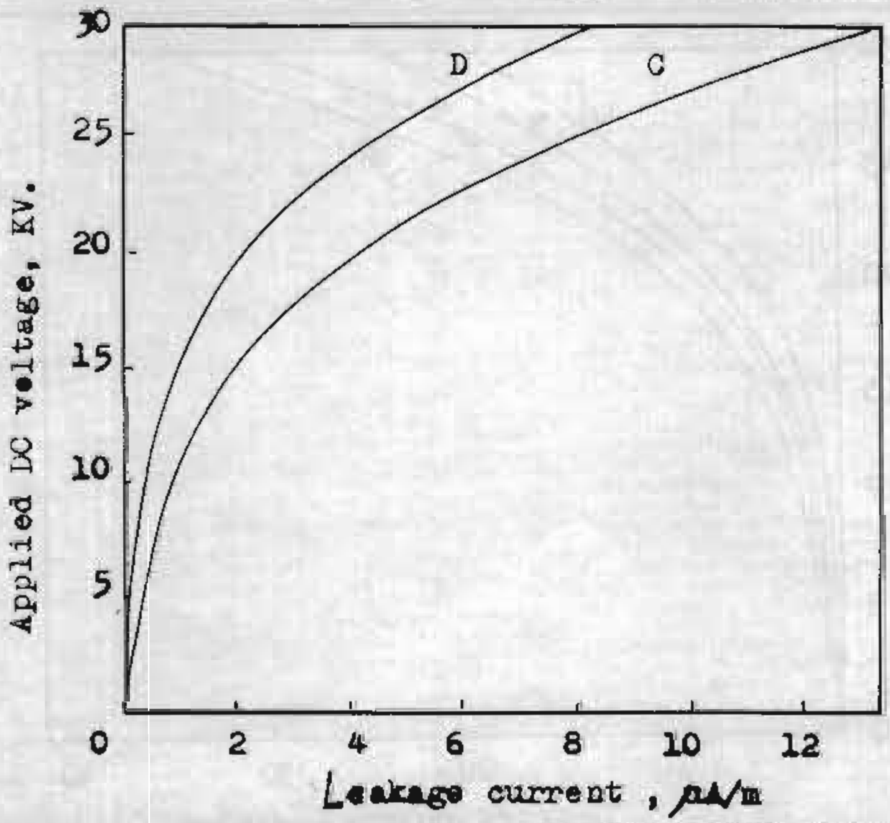
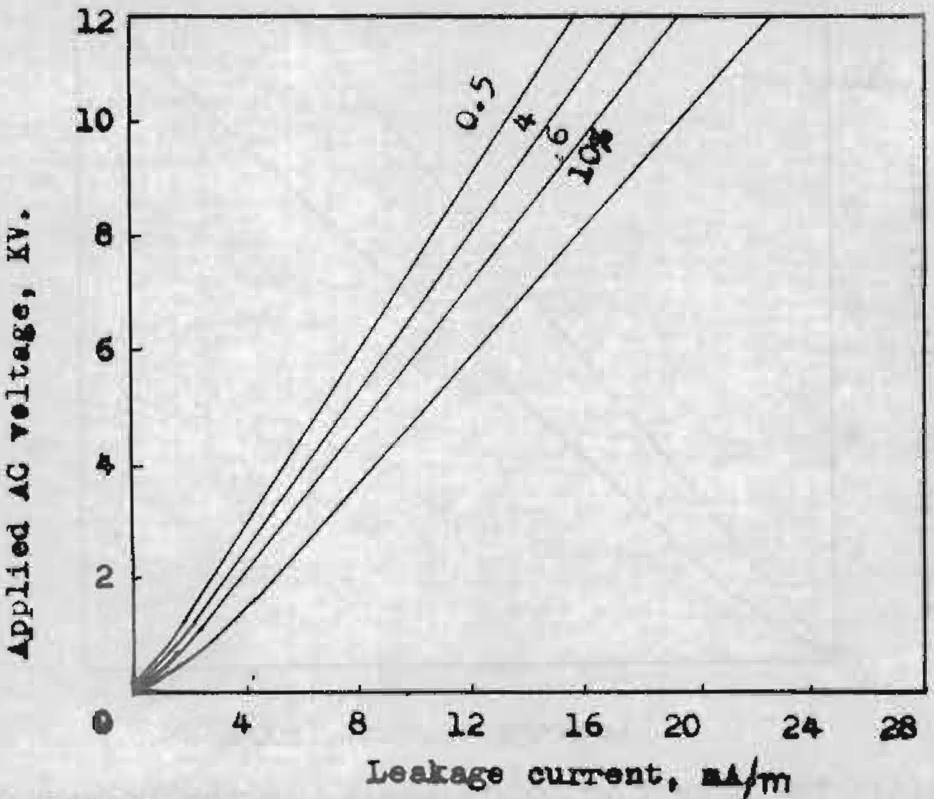


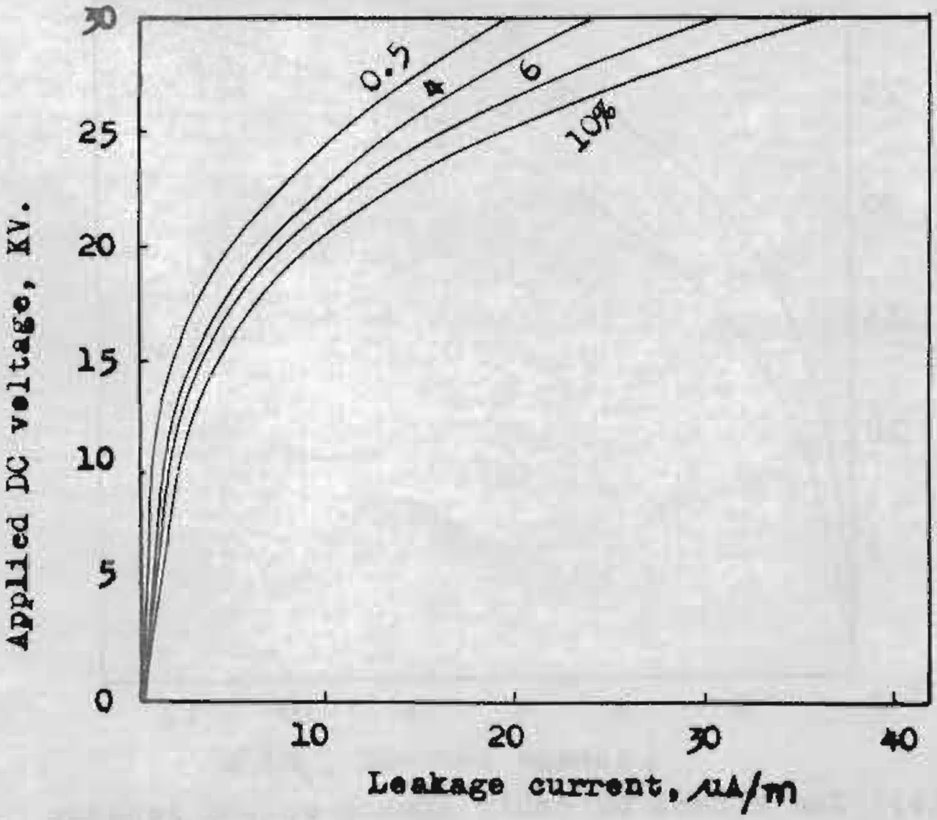
Fig(5): The effect of cable ageing on the leakage current under AC voltage (r.m.s.)



Fig(6): The effect of cable ageing on the leakage current under DC voltage of positive polarity.



Fig(7): The effect of moisture content on the leakage current under applied AC voltage of power cable between core and sheath.



Fig(8): The effect of moisture content on the leakage current under applied DC voltage of positive polarity.