

METHOD FOR DIAGNOSING AN INSULATION DETERIORATION
OF A POWER CABLE

FIELD OF THE INVENTION

The invention relates to a method for diagnosing
5 an insulation deterioration of a power cable, and more
particularly to a method for diagnosing an insulation
deterioration of a power cable in which the insulation
deterioration of a power cable such as a rubber
insulated power cable, a plastic insulated power cable
10 etc. is detected under a state that a rated line
voltage is applied to a power cable system.

BACKGROUND OF THE INVENTION

It has been clarified in the art that an
insulation deterioration of a power cable such as a
15 rubber or plastic insulated power cable is mainly
caused by the absorption of moisture into the solid
insulation material to which a rated line voltage is
applied. In the circumstance, water tree is induced in
the insulation material, and is then developed therein
20 to finally result in a breakdown of the power cable.
Therefore, a method for detecting the insulation
deterioration including water tree is required to be
established, thereby avoiding the breakdown of an
insulation material for a power cable in advance.

25 One type of a conventional method for diagnosing
an insulation deterioration of a power cable comprises
steps of applying a DC high voltage to an insulation of

the power cable, and detecting leakage direct current flowing through the insulation, so that the insulation deterioration is diagnosed dependent on a level of the leakage direct current. The other type of a conventional method for diagnosing an insulation deterioration of a power cable comprises steps of applying a DC voltage to the power cable, and analyzing motion and state of electrons in an insulation thereof to detect the insulation deterioration of the power cable.

In the conventional methods, however, there is a disadvantage that these methods are not applied to a power cable to which a rated load voltage is applied to supply electric power to actual loads, because the aforementioned DC voltage which is determined in diagnosis conditions is applied to the power cable. Even worse, there is a further disadvantage that the insulation deterioration is badly promoted to result in the breakdown of the power cable in some case dependent on a degree of the insulation deterioration, because the diagnosing DC high voltage is applied to the power cable.

In view of these situations, the inventors have conducted research and development for a diagnosis of an insulation deterioration intensively, and found that a direct current component is included in charging current flowing through an insulation of a cross linked polyethylene insulated poly-vinylchloride sheathed

cable (simply defined "CV cable" hereinafter) to which an AC voltage is applied in a case where the insulation is deteriorated by water tree. Further, the inventors have concluded that an insulation deterioration of a CV cable could be detected in accordance with a magnitude and a polarity of the direct current component under a state that the CV cable has supplied electric power to actual loads connected thereto. In this diagnosis of an insulation deterioration, a grounding conductor of the CV cable is utilized to detect charging current. Therefore, the diagnosis method is a very safe method for operators.

In a case where the insulation deterioration is diagnosed in accordance with the magnitude and the polarity of the direct current component as described above, however, experienced knowledge and much labor are required to obtain precise diagnosis results. This is because direct current component measured in a CV cable in an actually installed site ranges nA to μ A widely, and it must be decided to what extent the direct current component is affected by stray earth current, especially, where the direct current component is in the range of nA. A minute level of the stray current flows from the ground through a corrosion-proof layer (generally called "sheath") of the CV cable thereto where an insulation resistance value of the corrosion-proof layer is decreased down to a small

value, although the insulation resistance value is more than 2,000 M Ω at the time of manufacture and installation thereof. For this reason, it is necessary to measure an insulation resistance of the corrosion-
5 proof layer and to detect the presence or non-presence of a power source providing direct current potential to be applied to the corrosion-proof layer. This is a reason why much labor is needed as described above.

In a case where it is decided that a measured
10 current value is affected by the stray current, the direct current component from the CV cable and the stray current from the ground must be separated from each other as precisely as possible, so that the insulation deterioration is diagnosed based on the
15 separated direct current component.

For this purpose, a method for diagnosing an insulation deterioration of a power cable in which a direct current component is precisely detected as deterioration signal produced in a power cable having
20 water tree in an insulation thereof has been proposed in Japanese Patent Application No. 61-286972 filed on December 2, 1986 (Japanese Patent Laid-open No. 63-139261 laid-open on June 11, 1988). The method for .pa
25 diagnosing an insulation deterioration of a power cable comprises steps of measuring first positive and negative direct current components by applying positive and negative DC voltages across a metal shielding layer of a rubber or plastic insulated power cable and the

ground in the presence of an electric resistance therebetween respectively, measuring a second direct current component without the resistance by applying no DC voltage across the metal shielding layer and the ground, and separating direct current component and stray current included in charging current of the rubber or plastic insulated power cable in calculation based on the first positive and negative direct current components and the second direct current component, so that the insulation deterioration of the rubber or plastic insulated power cable is diagnosed in accordance with the separated direct current component.

According to the method for diagnosing an insulation deterioration of a power cable as proposed in the Japanese Patent Application No. 61-286972, however, there are disadvantages that operation in which the three direct current components are measured is troublesome, although the precise measurement thereof can be realized, and that there is limitation in decreasing a calculation amount, because the direct current component and the stray current are separated in the calculation based on the three direct current components.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the invention to provide a method for diagnosing an insulation

deterioration of a power cable in which a working amount in measuring a direct current component is decreased.

It is a further object of the invention to provide a method for diagnosing an insulation deterioration of a power
5 cable in which stray current from the ground is calculated in a simple calculation of less calculating amount.

According to the invention, there is provided a method for diagnosing an insulation deterioration of a power cable comprising, measuring charging current flowing from said
10 power cable, to which a rated AC voltage is applied, through a grounding conductor connected to a metal shielding layer of said power cable to the ground, using the measured charging current to calculate stray current flowing from the ground to said power cable in accordance with ground
15 potential, detecting a direct current component of said charging current, and calculating an intrinsic direct current component by subtracting said stray current from said direct current component, wherein said insulation deterioration is diagnosed in accordance with the level of
20 said intrinsic direct current component.

The diagnosis of the insulation deterioration caused by water tree induced in an insulation such as rubber, plastic etc. is based on the calculated intrinsic direct current component. Simultaneously with the calculation of
25 stray current, the charging current is supplied to a low pass filter through which only a direct current component is passed.

The invention will be described in more detail in conjunction with appended drawings wherein,

Fig. 1 is an explanatory diagram showing a conventional method for diagnosing an insulation deterioration of a power cable,

Fig. 2 is a circuit diagram showing an equivalent circuit corresponding to a circuit shown in Fig. 1,

Fig. 3 is an explanatory diagram showing a method for diagnosing an insulation deterioration of a power cable in an embodiment according to the invention,

Fig. 4 shows a waveform of charging current,

Figs. 5A to 5C and Figs. 6A to 6C are explanatory diagrams showing motion and state of electrons and holes in an insulation having water tree therein, and

Fig. 7 is an explanatory diagram for explaining a calculation in which stray current I_s is obtained.

20 DESCRIPTION OF PREFERRED EMBODIMENTS

Before explaining a method for diagnosing an insulation deterioration of a power cable in an embodiment according to the invention, the aforementioned conventional method as proposed in the Japanese Patent Application No. 61-286972 will be explained.

Fig. 1 shows an apparatus by which the conventional method is carried out and which comprises a capacitor 3 connected to a metal shielding layer (not shown) of a CV cable 2, a DC power supply 4 for applying positive and negative DC voltages to the metal shielding layer, a low pass filter 5 for selecting a direct current component from charging current, and a resistance R_d for detecting a current value of a direct current component. The CV cable 2 is connected through cable head terminals 2a to a high voltage bus 1.

Fig. 2 shows an equivalent circuit which corresponds to the apparatus of Fig. 1, and is composed of a meter M for detecting a direct current I_{DC} flowing from the CV cable 2, an insulation resistance R_s of a corrosion-proof layer of the CV cable 2, a potential difference E_s between the corrosion-proof layer and the ground, a DC resistance r of the low pass filter 5, the resistance R_d , and a current restriction resistance R , a DC power supply potential E and switches Sw_1 and Sw_2 respectively included in the DC power supply 4.

In operation, the direct current component is detected by measuring a terminal voltage across the resistance R_d . In more detail, a direct current component I_0 is defined as a current which flows through the resistance R_d where the switch Sw_1 is turned on, while the switch Sw_2 is turned off, and direct current components $I(+E)$ and $I(-E)$ are defined

as positive and negative direct current components which flow through the resistance R_d where the Sw_2 is turned on to apply positive and negative DC power supply potentials E_s (+E and -E) to the circuit, while
 5 the switch Sw_1 is turned off.

Here, the direct current component I_o , the positive direct current component $I(+E)$, and the negative direct current component $I(-E)$ are defined in the following equations (1), (2) and (3).

$$10 \quad I_o = I_{dc} \times \frac{R_s}{R_A} + \frac{E_s}{R_A} \dots\dots\dots (1)$$

$$I(+E) = I_{dc} \times \frac{R_s}{R_B} + \frac{E_s}{R_B} + \frac{E}{R_B} \dots\dots\dots (2)$$

$$I(-E) = I_{dc} \times \frac{R_s}{R_B} + \frac{E_s}{R_B} - \frac{E}{R_B} \dots\dots\dots (3)$$

where R_A is $(R_s + R_d + r)$, and R_B is $(R_s + R_d + R + r)$.

15 In the above equations (1), (2) and (3), the current components I_o , $I(+E)$ and $I(-E)$ are values to be measured, and the resistances R_s , R_d , r and R , and the DC power supply potential E are known values.

In experiments ever conducted, it has been
 20 confirmed that a corrosion-proof layer is damaged such that a metal shielding layer is exposed to the ground, if the value of the insulation resistance R_s is less than 100 K Ω . Therefore, the equations (1), (2) and (3) are solved in the assumption that the value of the

insulation resistance R_s is equal to or more than 100 $K\Omega$ ($R_s \geq 100 K\Omega$). At the same time, the value of the current detecting resistance R_d is required to be equal to or less than 100 $K\Omega$ ($R_d \leq 100 K\Omega$), so that error which is induced based on a time constant etc. can be avoided in measuring the direct current components.

Assuming the conditions " $R_s \geq 100 K\Omega$ " and " $R_d \leq 100 K\Omega$ ", the equation (1) is modified as the equation (4).

$$I_o = I_{dc} + \frac{E_s}{R_A} \dots\dots\dots (4)$$

In accordance with the equation (4), the direct current component I_{dc} from the CV cable 2 is obtained as follows.

$$I_{dc} = I_o - \frac{E_s}{R_A} \dots\dots\dots (5)$$

The second term of the right side in the equation (5) expresses stray current I_s flowing through the corrosion-proof layer of the CV cable 2 as defined in the equation (6).

$$I_s = \frac{E_s}{R_A} \dots\dots\dots (6)$$

The insulation resistance R_s of the corrosion-proof layer and the potential difference E_s between the corrosion-proof layer and the ground are calculated to provide the equations (7) and (8), so that the direct current component I_{dc} from the CV cable 2 and the stray

current I_s are obtained in the equations (5) and (6).

$$R_s = \frac{2E}{I(+E) - I(-E)} - (R_d + R + r) \dots\dots\dots (7)$$

$$E_s = \frac{1}{2} \left[\frac{R_B}{R_s} [I(+E) - I(-E)] - 2I_o \right] / \left(\frac{1}{R_s} - \frac{1}{R_A} \right) \dots\dots\dots (8)$$

5 As clearly understood from the above, the
aforementioned disadvantages are never avoidable in the
conventional method.

Next, a method for diagnosing an insulation
deterioration of a power cable in an embodiment
10 according to the invention will be explained.

Fig. 3 shows an apparatus for diagnosing an
insulation deterioration of a power cable in which a
method for diagnosing an insulation deterioration of a
power cable in an embodiment according to the invention
15 is carried out. The apparatus comprises a charging
current detecting circuit 31 connected through a common
grounding conductor 37 to a metal shielding layer (not
shown) of a CV cable 2 for detecting charging current
flowing through the CV cable 2 when an AC voltage is
20 applied to the CV cable 2, a low pass filter 32 for
passing a direct current component I_{DC} of the charging
current, a stray current detecting circuit 33 for
detecting stray current I_s in accordance with the
charging current, a DC current detecting circuit 34 for

detecting the direct current component I_{DC} , a calculation circuit 35 for subtracting the stray current I_s from the direct current component I_{DC} to provide an intrinsic direct current component, and a
5 diagnosis circuit 36 for deciding to what extent an insulation of the CV cable 2 is deteriorated due to water tree. The CV cable 2 is connected through cable head terminals 2a to a high voltage bus 1.

Fig. 4 shows a waveform 41 of the charging
10 current detected in the charging current detecting circuit 31. The waveform 41 has distortions 41A and 41B in the vicinity of peak value, when the insulation of the CV cable 2 is deteriorated in the presence of water tree. In more detail, when negative AC voltage
15 53 as shown in Fig. 5A is applied to the CV cable 2 including a conductor 54, an inner semiconductive layer 55, a cross-linked polyethylene insulation 56, and an outer semiconductive layer 58 in which water tree 57 occurs as shown in Fig. 5B, electrons 59 are injected
20 from tips of the water tree 57 into the insulation 56. Then, when positive AC voltage 53 as shown in Fig. 6A is applied to the CV cable 2, a portion of the electrons 59 is absorbed on the side of the water tree 57, and the other of the electrons 59 is neutralized
25 with holes 60 injected into the insulation 56. Thus, the waveform 41 of the charging current becomes asymmetrical with the distortions 41A and 41B as shown in Figs. 5C and 6C, because motion and state of the

electrons 59 are different between the negative and positive half periods of the AC voltage 53. The charging current 41 is supplied to the low pass filter 32 to pass the direct current component I_{DC} therethrough which is then detected in the direct current detecting circuit 34.

Fig. 7 shows charging current flowing through a common grounding conductor, wherein the charging current is of an added value of zero-phase-sequence current I_0 and stray current I_s induced by the ground potential. In Fig. 7, a horizontal solid line 70A is for zero level of the zero-phase-sequence current I_0 to which the stray current I_s is added, and a horizontal dotted line 70B is for zero level of the zero-phase-sequence current I_0 to which the stray current I_s is not added. Further, a peak value I_m is for the zero-phase-sequence current I_0 , and the charging current crosses the zero level line 70A at the time of t_0 , t_1 , t_2 If it is assumed that the charging current is of 50 Hz, such that the period of the zero-phase-sequence current I_0 is 20 (= 10 + 10) m sec, and the zero-phase-sequence current I_0 crosses the zero level line 70B with a time difference Δt from the zero crossing points of the charging current. Therefore, the stray current I_s is obtained in the equation (9).

$$I_s = I_m \sin \frac{t}{10} \dots\dots\dots (9)$$

$$\begin{aligned} \text{where } t &= 1/2 [10 - (t_2 - t_1)] \\ &= 1/2 [(t_1 - t_0) - 10] \end{aligned}$$

Accordingly, the stray current I_s generated due
 5 to a potential difference between the shielding layer
 and the ground is precisely obtained by measuring the
 times t_0 , t_1 and t_2 .

The charging current is also supplied to the
 stray current detection circuit 33 in which the stray
 10 current I_s is calculated in accordance with the
 equation (9), and the calculated result of the stray
 current I_s is supplied to the calculation circuit 35
 along with the direct current component I_{DC} from the
 direct current detecting circuit 34. In the
 15 calculation circuit 35, the intrinsic direct current
 component I_{DCI} is obtained in the equation (10).

$$I_{DCI} = I_{DC} - I_s \dots\dots\dots (10)$$

The intrinsic direct current component I_{DCI} is
 supplied to the diagnosis circuit 36 in which the CV
 20 cable 2 is diagnosed in accordance with the intrinsic
 direct current component I_{DCI} as to whether the cross
 linked polyethylene insulation is deteriorated.

In accordance with the above described
 operation, the intrinsic direct current component I_{DCI}
 25 was obtained in five samples of CV cables which have
 been actually used for durations described in Table 1
 under a rated voltage of 6 KV. After measuring the

intrinsic direct current component I_{DCI} under the actually installed state, the CV cables were removed from the installing sites to be brought into an experiment room in which the CV cables were measured to provide the intrinsic direct current component I_{DCI} under a state that the CV cables were insulated from the ground to prevent the stray current I_s from flowing from the ground to the CV cables. Then, the CV cables were subject to an AC breakdown test, so that the insulation deterioration of the CV cables were examined. Finally, the CV cables were dismantled to check the generation of the water tree visually.

The table 1 shows the details of the CV cables, the insulation deterioration of which were diagnosed and examined as described above, and Table 2 shows the results of the measurements and the tests as conducted above.

TABLE 1

	CABLE 1	CABLE 2	CABLE 3	CABLE 4	CABLE 5
USED DURATION (YEARS)	3	11	15	17	20
KINDS	C V	C V	C V	C V	C V
VOLTAGE (K V)	6.6	6.6	6.6	6.6	6.6
SIZE (mm ²)	150	150	38	250	60

TABLE 2

			CABLE 1	CABLE 2	CABLE 3	CABLE 4	CABLE 5
MEASURED RESULTS IN ACTUALLY INSTALLING SITE	I_{DC} (nA)		7	18.2	69	180	235
	I_s (nA)		7	16	63	37	70
	I_{DCI} (nA) ($I_{DC} - I_s$)		0	2.2	6	43	165
MEASURED RESULTS IN EXPERIMENT ROOM AFTER REMOVAL	I_{DCI} (nA)		<0.1	2.2	6	43	165
	AC BREAKDOWN VOLTAGE (KV) -		85	25	20	15	10
	WATER TREE	PRESENCE	NO	YES	YES	YES	YES
		MAXIMUM LENGTH (mm)	-	2.4	3.0	3.5	3.5

As clearly understood from the data in the Table 2, the stray current I_s from the ground is precisely measured in a method for diagnosing an insulation deterioration of a power cable according to the invention, so that the intrinsic direct current component I_{DCI} is also precisely obtained in accordance with the measured stray current I_s .

The dismantling results verify that the water tree is generated in the cables 2 to 5 in which the intrinsic direct current component I_{DCI} is observed, and the AC breakdown voltage is lowered therein. Further, the water tree becomes longer, and the AC breakdown voltage becomes lower, as the intrinsic

direct current I_{DCI} becomes larger.

As described above, it is understood that the intrinsic direct current component I_{DC} which is an insulation deterioration signal is precisely measured
5 under a state that a rated AC voltage is applied to a power cable in an actually installing site, so that the insulation deterioration is determined with a predetermined precision.

Although the invention is embodied in a CV
10 cable, it may be applied to a power cable having an insulation of a material such as rubber etc. Further, it may be applied to a single core cable or a cable having multi-cables stranded in a conduit.

Although the invention has been described with
15 respect to specific embodiment for complete and clear disclosure, the appended claims are not to thus limited but are to be construed as embodying all modification and alternative constructions that may occur to one skilled in the art which fairly fall within the basic
20 teaching herein set forth.

CLAIMS

1. A method for diagnosing an insulation deterioration of a power cable comprising,

measuring charging current flowing from said power
5 cable, to which a rated AC voltage is applied, through a
grounding conductor connected to a metal shielding layer of
said power cable to the ground,

using the measured charging current to calculate stray
current flowing from the ground to said power cable in
10 accordance with ground potential,

detecting a direct current component of said charging
current, and

calculating an intrinsic direct current component by
subtracting said stray current from said direct current
15 component,

wherein said insulation deterioration is diagnosed in
accordance with the level of said intrinsic direct current
component.

20 2. A method for diagnosing an insulation deterioration
of a power cable according to claim 1,

wherein said stray current (I_s) is calculated in
following equations,



$$I_s = I_m \sin \frac{\Delta t}{T} \cdot \pi, \text{ and}$$

$$\begin{aligned} \Delta t &= 1/2 [T/2 - (t_2 - t_1)] \\ &= 1/2 [(t_1 - t_0) - T/2] \end{aligned}$$

where I_m is the peak value of a zero-phase-
5 sequence current of said charging current, T is the
period of said zero-phase-sequence current, and t_0 , t_1
and t_2 are the times of zero crossing points of said
charging current.

3. A method for diagnosing an insulation
10 deterioration of a power cable according to claim 1,

wherein said direct current component is
obtained by passing said charging current through a low
pass filter.

4. A method as claimed in claim 1, substantially as
described with reference to figures 3 to 7 of the drawings.
