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V－T Characteristics of Oil Impregnated Paper Insulation and the Drawing by a Computer

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1. Introduction

The dielectrics of oil impregnated paper, which impregnates insulating oil to the insulating layer formed by laying several sheets of insulating paper, is widely used as dielectrics for power capacitors, transformers and power cables.

It is a known fact that, when constant AC voltaqe is imposed to the dielectrics of oil impregnated paper, T, the time to breakdown after imposing voltage, greatly depends upon the imposed voltage V, and conspicuous V－T characteristics is observed.

This paper reports V－T characteristics of oil impregnated paper which impregnates mineral oil or alkylnaphthalene to varied insulating paper constructions, including dielectric breakdown mechanism, and effects of the insulation construction and of the insulating oil. Based on the results the program to draw V－T characteristics of optional oil impreqnated paper on the X－Y plotter with a computer was developed, whose applications are also reported in this paper.

2. Specimen and measurement method

As the specimen, several sheets of varied types of insulating paper with different thickness, density and air tightness were layed, they were wound with the aluminum foil electrodes with about 10μm thickness, about 0.3m width and about 5m length, to form a condenser type structure, and they were held at about 15℃ in the vacuum of 1 torr or under for 4 days to fully dry, then impregnated in vacuum with the insulating oil having been degassing and dehumidifying processed in 1 torr or under at about 70℃. Table 1 and Fig. 1 show characteristics of the insulating oil, and Table 2 shows types of the insulating paper used, the insulation construction and types of impregnated insulating oil.

V－T characteristics were obtained by measuring, T, the time until dielectric breakdown after imposing voltage of 60Hz with different voltage values V to the specimen.[1),2),3)]

Types of insulating oil applied to specimens were mineral oil (JIS C 2320 Type 1, No. 1, hereafter called oil M) used for power capacitors and alkylnaphthalene (JIS C 2320 Type 4, No. 1, hereafter called oil S).

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Table 1. Properties of insulating oils applied to specimen

Property	Insulating oil	
	Oil M	Oil S
Specific gravity (15/4℃)	0.880	0.955
Kinematic viscosity (30℃), cSt	8.7	8.5
Pour point, ℃	−30.0	−47.5
Flash point, ℃	134	144
Evaporation, %	0.22	0.12
Thermal expansion, 10^{-4}/℃	6.5	7.2
Thermal conductivity, kcal/m.h.℃	0.095	0.103
Dielectric constant (60 Hz, 80℃)	2.18	2.48
Tan δ (60 Hz, 80℃), %	0.04	0.05
Volume resistivity (80℃), Ω.cm	8×10^{14}	6×10^{14}
Dielectric strength, kV/2.5 mm	70	85
Gas generating voltage, kV/mm	46	72
Aromaticity, %	12	62.5

Table 2 Construction of insulations

Symbol	Impregnated insulating oil	Insulating paper and insulation construction				
		Density d(g/cm^3)	Air tightness(cc/5min)	Thickness ℓ_1(μm)	Number of sheet n	Total thickness ℓ (μm)
A	Oil M	1.14	<1	16	2~6	32~ 96
B		1.17	〃	20	〃	40~120
C		0.90	〃	20	〃	〃
D		0.82	40	42	2~5	84~210
E		0.76	25	58	3~6	174~348
F	Oil S	1.10	<1	9	3	27
G		1.10	〃	15	3	45
H		0.78	5	25	4	100
J		1.10	<1	35	3	105
K		1.33	〃	18	6	108
L		0.82	15	50	5	250
M		0.82	15	55	5	275

3. Measurement results of V−T characteristics

Fig. 2 shows measured V−T characteristics of specimen C impregnated with oil M. Fig. 3 and Fig. 4 show the results of three sheets and five sheets layers of specimens, A−E, impregnated with oil M, respectively. Fig. 5 shows V−T characteristics of specimens, F−M, impregnated with oil S.

As shown in Fig. 2−5 of the logarithmic scales the V−T characteristics is composed of the short time region with little curved line and the long time region with much curved line, whose lines cross at around 10^2−10^3 seconds. The dotted lines show the extrapolation of the actual measurements, made with the equations (19) and (20) stated below. It is understood that in the oil impregnated paper the insulating paper and the insulating oil layer are lined in serial, therefore, imposed AC voltage devides the electric field in the inverse proportion of the dielectric constant at the insulating paper and the insulating oil layer. The insulating oil layer with lower dielectric constant receives higher electric field,

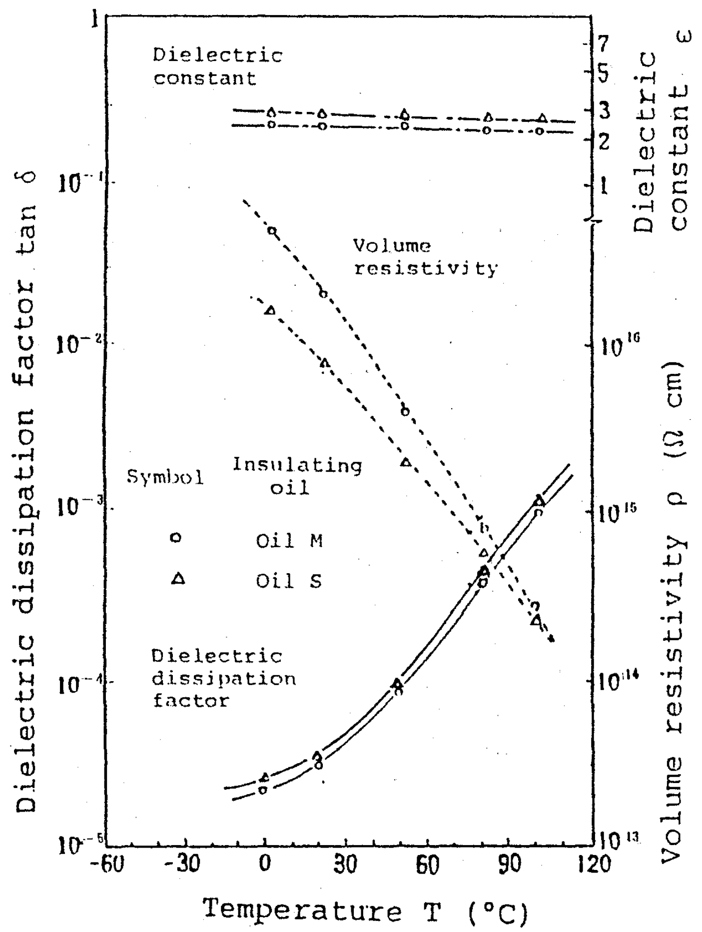

Fig.1 Dielectric characteristics of insulating oils

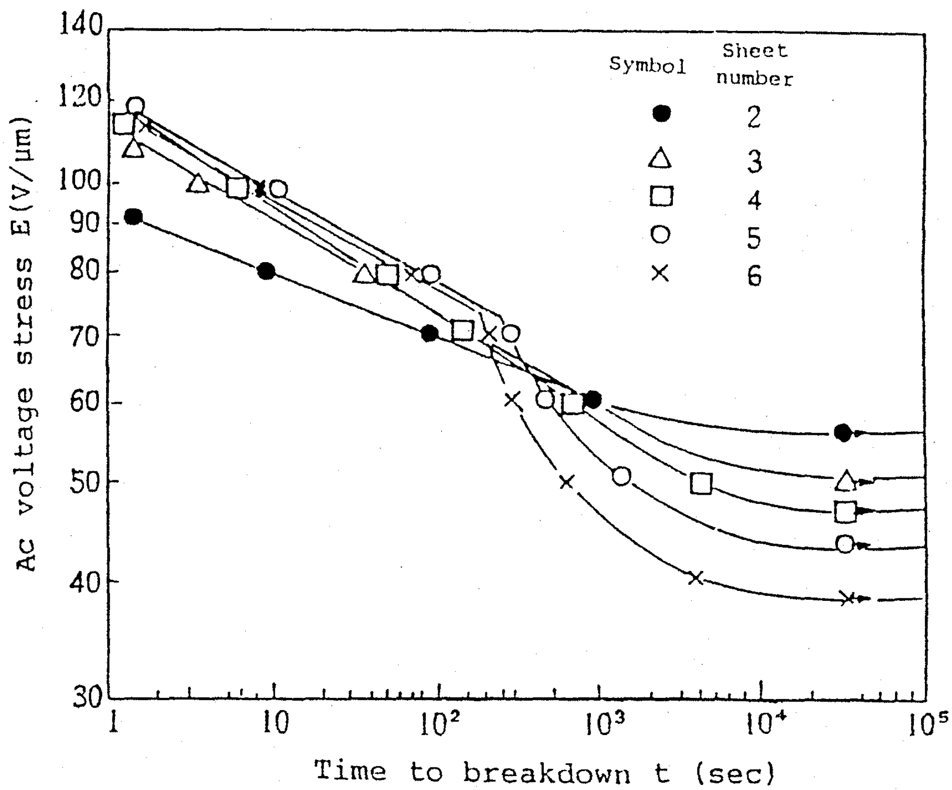

Fig.2 V−T characteristics of oil M impregnated specimen

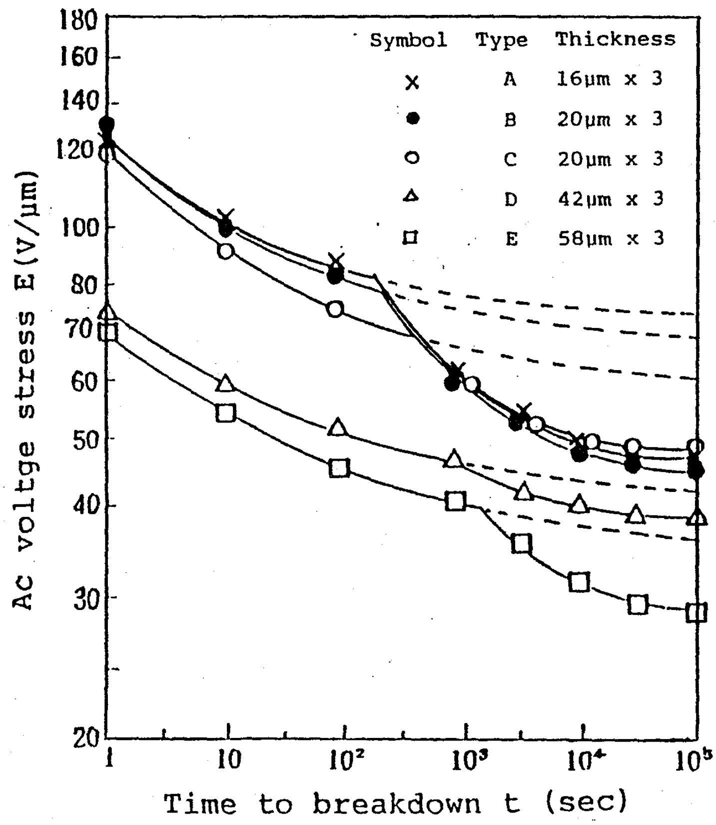

Fig.3 V−T characteristics of oil M impregnated paper of three sheets

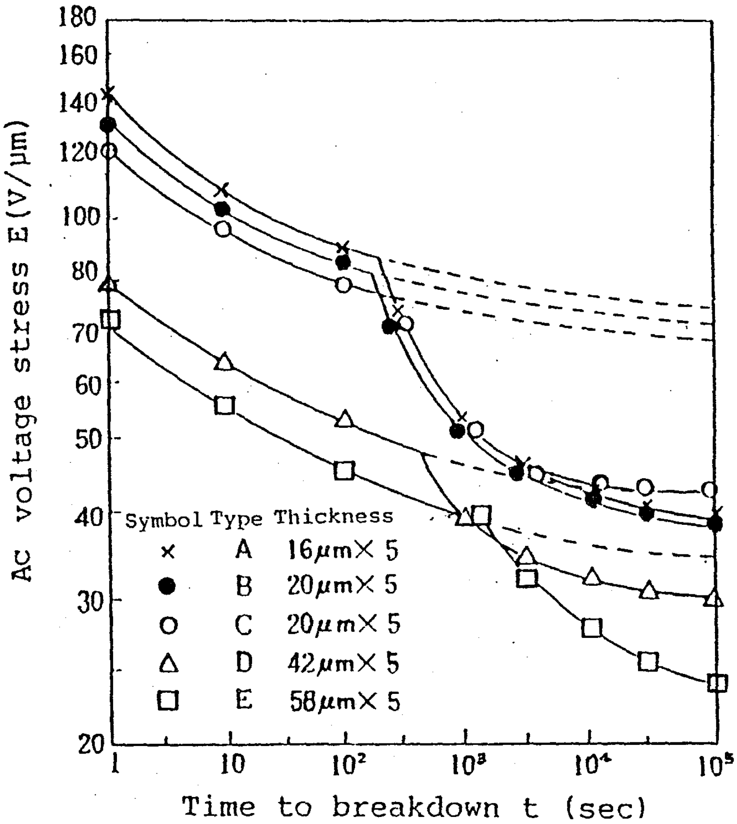

Fig.4 V−T characteristics of oil M impregnated paper of five sheets

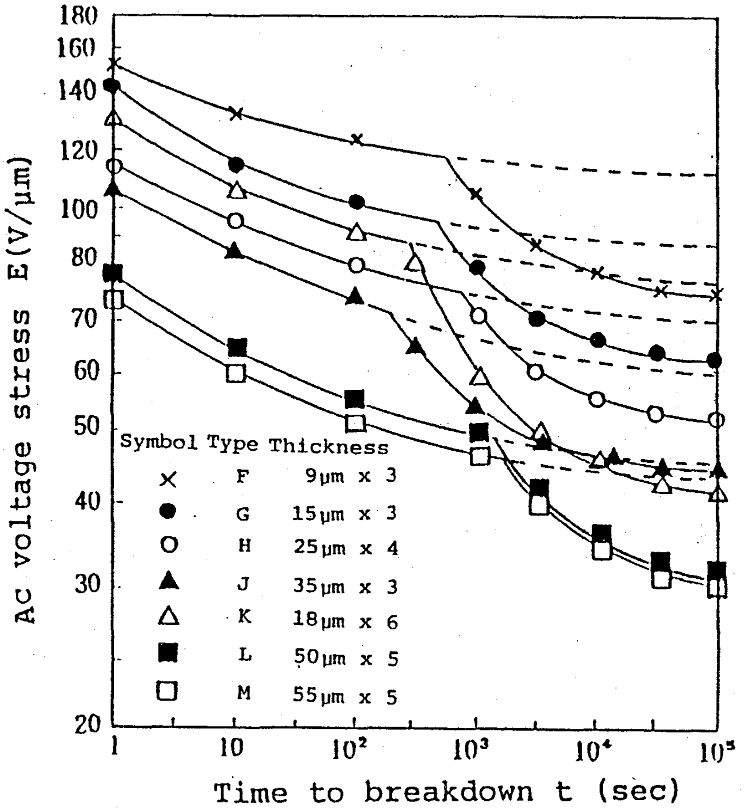

Fig.5 V−T characteristics of oil S impregnated paper

and due to lower insulation resistance of insulating oil, the insulating oil layer suffers partial breakdown earlier than the insulating paper.

Imposing voltage corresponding to the voltage starting partial breakdown at the insulating oil layer causes gradual abrasion at the insulating paper part and finally results in complete breakdown between the electrodes. This voltage, therefore, is the long term ac endurance stress E_∞ of the long time reqion of V−T characteristics. In raising the ac imposed voltage stress higher than E_∞, the higher is the stress, the greater is the damage at the insulating oil layer and the shorter is the time to complete breakdown between the electrodes, revealing the long time region of V−T characteristics.

Further raising of the ac imposed voltage stress reaches the electric field directly breaking the insulating paper, indicating the long term ac endurance stress E'_∞ of the short time region of V−T characteristics, but it is masked by the long time region of the V−T characteristics.

At this short time region, the higher is the ac imposed voltage stress exceeding E'_∞ the shorter is the time to reach complete breakdown between the electrodes, revealing the short time region of V−T characteristics.

As stated above, whereas in the long time region the partial breakdown of the oil layer advances, causing indirect dielectric breakdown of the insulating paper, in the short time region the insulating paper is directly broken down, shortening the time to breakdown remarkably due to rise in voltage, decreasing inclination of the V−T characteristics of the

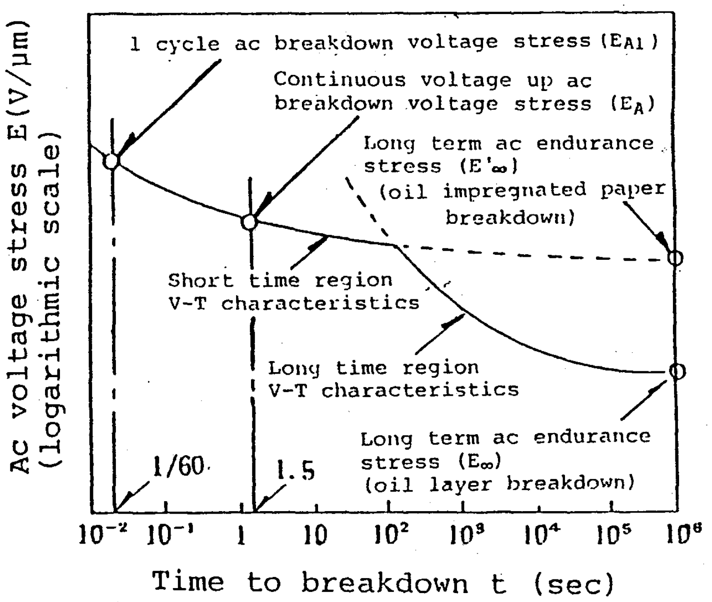

Fig.6 V—T characteristics of oil impregnated paper

short time region and revealing the V—T characteristics as shown in Fig. 6.

4. Long time region V—T characteristics

As stated above, in the long time region V—T characteristics of oil impregnated paper, the higher is the imposed ac voltage stress E than the long term endurance stress E_∞ determined by breakdown of the insulating oil layer, the greater is the breakdown of the oil layer, intensifying abrasion of the insulating paper, and accordingly the larger is $(E-E_\infty)$, the shorter is the time to breakdown t. It is reasoned, therefore, the relation of the two can be obtained by the below equation.

$E-E_\infty = E_{L1}t^{-\gamma}$ ··(1)

Where E_{L1} and γ are constants determined by the dielectric. The long term ac endurance stress E_∞ is adequately determined with the actual measurements of the long time region V—T characteristics of each oil impregnated paper, and the relation between $(E-E_\infty)$ and t is obtained. It is shown in Fig. 7 and 8, making straight lines in the graph of log—log scale, thus proving the correctness of the equation (1).

Table 3 and 4 show the long term ac endurance stress E_∞, thus obtained with these specimens.

The long term ac endurance stress of oil S impregnated specimen is ten—odd% higher than that of oil M impregnated specimen, due to higher breakdown strength of oil S . In Fig. 8, the average of $(E-E_\infty)$ of oil M impregnated paper of each sheet number and the average of $(E-E_\infty)$ of oil S impregnated paper. With these, the following equations are obtained.

(i) Oil M impregnated paper: $E = E_\infty + E_{L1}t^{-\gamma}$

$= E_\infty + 2{,}000^{-0.74}$ ································(2)

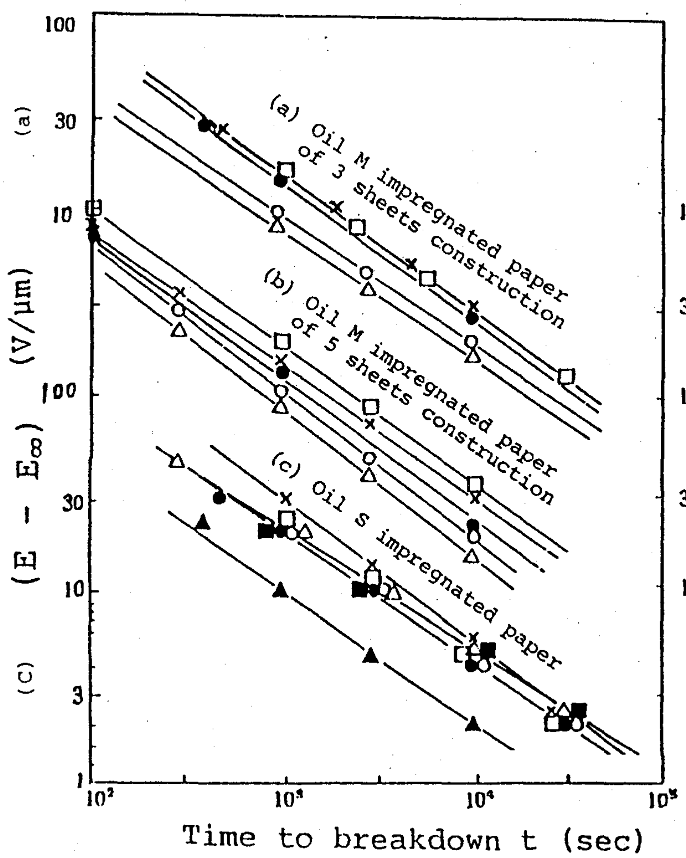

Fig.7 Relation between $E-E_\infty$ and time to breakdown

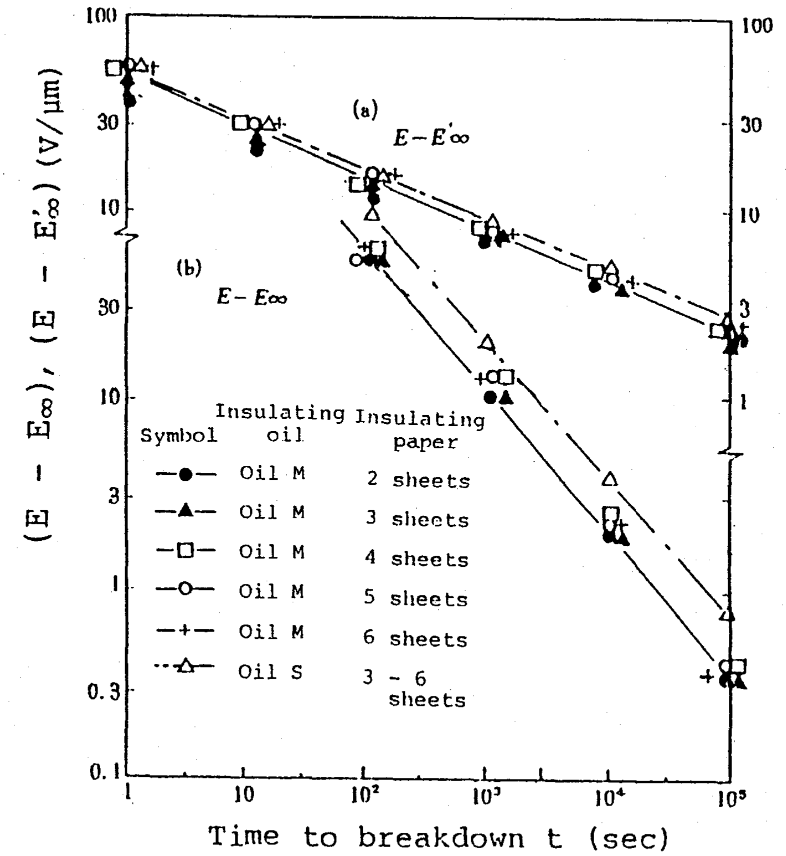

Fig.8 Relation between $E-E_\infty$ or $E-E'_\infty$ and time to breakdown

Table 3 Ac long term endurance stress of oil M impregnated paper

Symbol (density d)	Thickness × number $\ell_1 \times n$ (μm)	Breakdown stress E_∞ (V/μm)	Breakdown stress E'_∞ (V/μm)	E'_∞/E_∞	Symbol (density d)	Thickness × number $\ell_1 \times n$ (μm)	Breakdown stress E_∞ (V/μm)	Breakdown stress E'_∞ (V/μm)	E'_∞/E_∞
A	16×2	53	68	1.28	C	20×4	44	58	1.32
	3	46	70	1.52	(0.90g/cm³)	5	41	65	1.59
	4	41	74	1.80		6	38	66	1.74
(1.14g/cm³)	5	38	72	1.89	D	42×2	44	46	1.05
	6	36	70	1.94	(0.82g/cm³)	3	38	42	1.11
B	20×2	49	62	1.27		4	33	40	1.21
	3	45	66	1.47		5	30	40	1.33
	4	40	66	1.65	E	58×3	28	35	1.25
(1.17g/cm³)	5	38	68	1.79	(0.76g/cm³)	4	26	34	1.31
	6	36	66	1.83		5	24	32	1.33
C	20×2	56	58	1.04		6	22	32	1.45
(0.90g/cm³)	3	49	58	1.18					

Table 4 Ac long term endurance stress of oil impregnated paper specimen

Symbol	Insulating oil	Density of paper d (g/cm³)	Insulating thickness $\ell_1 \times n$ (μm)	E_∞ (V/μm) Oil M (F)	E_∞ (V/μm) Oil S (G)	(G)/(F)	E'_∞ (V/μm) Oil M (H)	E'_∞ (V/μm) Oil S (J)	(J)/(H)	(H)/(F)	(J)/(G)
A	Oil M	1.14	16×5	38	—	—	72	—	—	1.89	
B	〃	1.17	20×5	38	—	—	68	—	—	1.79	
C	〃	0.90	20×5	41	—	—	65	—	—	1.59	
D	〃	0.82	42×5	30	—	—	40	—	—	1.33	
E	〃	0.76	58×5	24	—	—	32	—	—	1.33	
—	〃	—	$\bar{X}$	34.2	—	—	55.4	—	—	1.60	
F	Oil S	1.10	9×3	(62)	73	1.18	(107)	106	0.99		1.45
G	〃	1.10	15×3	(51)	61	1.20	(78)	82	1.05		1.34
H	〃	0.78	25×4	43	50	1.16	62	66	1.06		1.32
J	〃	1.10	35×3	(37)	43	1.16	(45)	55	1.22		1.28
K	〃	1.33	18×6	(37)	39	1.05	(69)	74	1.07		1.90
L	〃	0.82	50×5	24	29	1.21	40	42	1.05		1.45
M	〃	0.82	55×5	26	29	1.12	41	42	1.02		1.45
—	〃	—	$\bar{X}$	46.3	40.0	1.16	63.1	66.7	1.06		1.46
Remarks				(1) In case of oil M impregnation, the breakdown voltage stress of 5 sheets construction is shown. (2) Values in ( ) are estimates obtained by Fig.9 and 12.							

(ii) Oil S impregnated paper: $E = E_\infty + 2{,}500t^{-0.70}$ ……………………………(3)

As shown in Fig. 8, $(E-E_\infty)$ at 10^5 seconds is 1 V/μm or under in oil M impregnated paper and around 1 V/μm in oil S impregnated paper, showing slight difference, which derives from absorptivity of gas generated in breakdown of insulating oil. It is considered that the higher is gas absorptivity of insulating oil, the higher is the breakdown voltage stress around 10^5 seconds exceeding the long term ac endurace stress E_∞.

Inclinations of lines on relation of $(E-E_\infty)$ and t are almost identical in oil M impregnated paper and oil S impregnated paper.

Fig. 9 shows the relation of between the long term ac endurance stress and the insulation thickness. The long term ac endurance stress E_∞ is determined by insulation thickness, regardless of sheet number n, and is normally shown by the following equations.

(i) Oil M impregnated paper: $E_\infty = E_\infty \ell^{-\delta} = 200\,\ell^{-0.36}$ ……………………(4)

(ii) Oil S impregnated paper: $E_\infty = 300\,\ell^{-0.41}$ ………………………………(5)

Where, $E_{\infty 1}$ is the proportional constant, equivalent to the long term ac endurance stress at $\ell = 1\,\mu m$ and δ is the constant determined by the dielectric.

The long time region V−T characteristics of oil impregnated paper with insulation thickness ℓ is obtained by substituting equations (4) and (5) into equations (2) and (3), as follows:

(i) Oil M impregnated paper: $E = E_{\infty 1}\ell^{-\delta} + E_{L1}t^{-Y}$

$= 200\ell^{-0.36} + 2{,}000t^{-0.74}$ ····················(6)

(ii) Oil S impregnated paper: $E = 300\ell^{-0.41} + 2{,}500t^{-0.70}$ ····················(7)

5. Long term ac endurance stress deribed from the breakdown voltage of oil layer

When ac voltage stress E_o is imposed to the oil impregnated paper, the voltage stress E_l applied to the insulating oil layer is obtained by the following equation.

$$E_o = \frac{\varepsilon_l}{\varepsilon_o} E_l \qquad \cdots\cdots(8)$$

When E_l reaches the dielectric breakdown voltage stress of the insulating oil E_{lb}, the stress E_o applied to the oil impregnated paper is the long term ac endurance stress E_∞, that is,

$$E_\infty = \frac{\varepsilon_l}{\varepsilon_o} E_{lb} \qquad \cdots\cdots(9)$$

The dielectric breakdown voltage of oil M[4] and oil S are measured by the insulating oil layer which is made by inserting several sheets of insulating paper between the flat disc

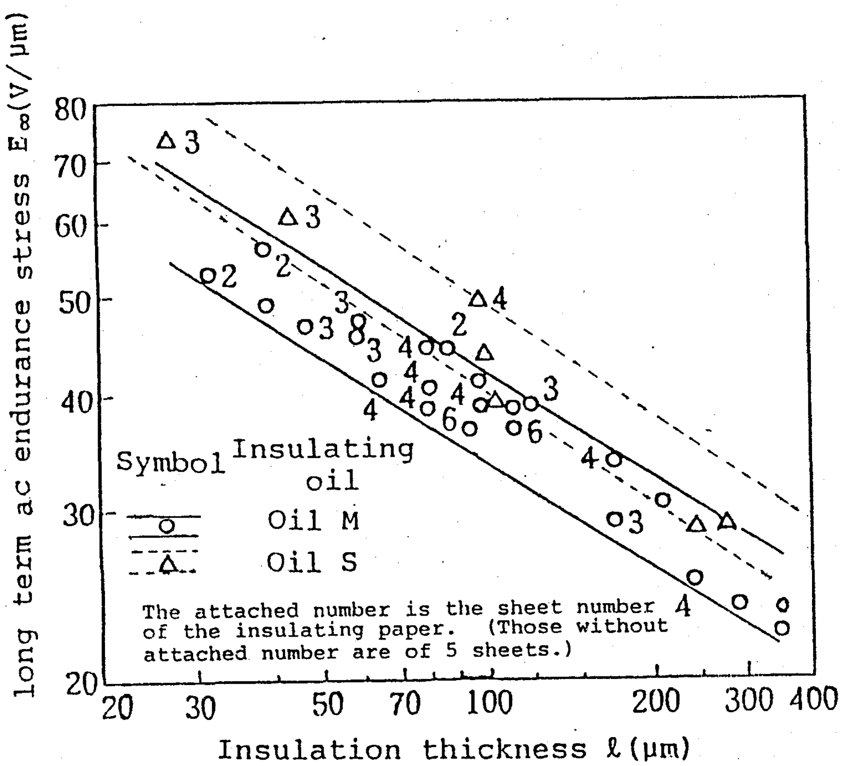

Fig.9 Relation between long term ac endurance stress and the insulation thickness

electrodes of diameter 70mm (electrode end : 7mmR) and punching a hole of diameter 10mm on the sheets, and E_{ib} is obtained from the result, Fig. 10 , as the function of oil layer thickness $\ell_i = \theta_i \ell$.

(i) Oil M: $E_{ib} = E_{ib1} \ell_i^{-k} = 260 \ell_i^{-0.33} = 260(\theta_i \ell)^{-0.33}$ ····················(10)

(ii) Oil S: $E_{ib} = 360 \ell_i^{-0.37} = 360(\theta_i \ell)^{-0.37}$ ·······································(11)

Here, E_{ib1} is the breakdown voltage stress of the insulating oil at $\ell_i = 1\,\mu m$, and k is the constant determined by the insulating oil.

By substituting equations (10) and (11) into equation (9),

(i) Oil M impregnated paper: $E_\infty = E_{\infty 1} \ell^{-0.33}$

$$= 260\,\theta_i^{-0.33} \frac{\varepsilon_i}{\varepsilon_o} \ell^{-0.33} \quad \cdots\cdots(12)$$

Where, $E_{\infty 1}$ is the same as $E_{\infty 1}$ in the equation (4).

(ii) Oil S impregnated paper: $E_\infty = 360\,\theta_i^{-0.37} \frac{\varepsilon_i}{\varepsilon_o} \ell^{-0.37}$ ··············(13)

When the density of the insulating paper is 0.8, 1.0 and 1.2g/cm³, θ_i, ε_i and ε_o at 20℃ are obtained as shown in Table 5 [5].

$E_{\infty 1}$ obtained by substitution of the above values into (12), (13) is also given in Table 5.

As shown above, when comparing the calculation values of $E_{\infty 1}$ and δ obtained theoretically with the breakdown voltage stress of the insulating oil shown in Fig. 10 and the actual measurement values stated in the equations (4) and (5), both are fairly identical and almost nothing influenced by the density of the insulating paper.

Table 5 Dielectric constant of oil impregnated paper and long term ac endurance stress

insulating oil	Oil M			Oil S		
Density of paper(g/cm³)	0.8	1.0	1.2	0.8	1.0	1.2
ε_i	2.20	2.20	2.20	2.50	2.50	2.50
ε_0	3.40	3.85	4.44	3.62	4.05	4.57
$\varepsilon_i/\varepsilon_0$	0.647	0.571	0.495	0.691	0.617	0.547
θ_i	0.475	0.345	0.215	0.475	0.345	0.215
$E_{\infty 1}$	215	211	214	328	330	348

6. Short time region V−T characteristics

As stated above, the short time region V−T characteristics of the oil impregnated paper appears when the ac imposed voltage stress is raised higher than the voltage stress E'_∞ where direct breakdown of the insulating paper impregnated with insulating oil begins, but the long time part after 10^3−10^4 seconds is masked by the long time region V−T characteristics.

The higher is the ac voltage stress E imposed to oil impregnated paper exceeding E'_∞, the shorter is the time to breakdown t, and the relation of the two is shown in the below equation.

$E - E'_\infty = E_{s1} t^{-\nu}$ ·······································(14)

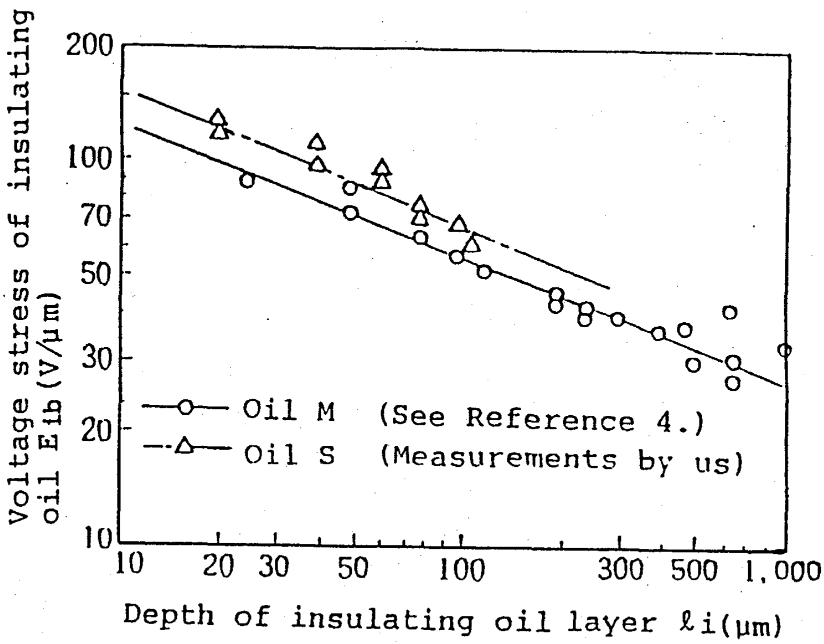

Fig.10 Relation between breakdown voltage stress and layer depth of the insulating oil

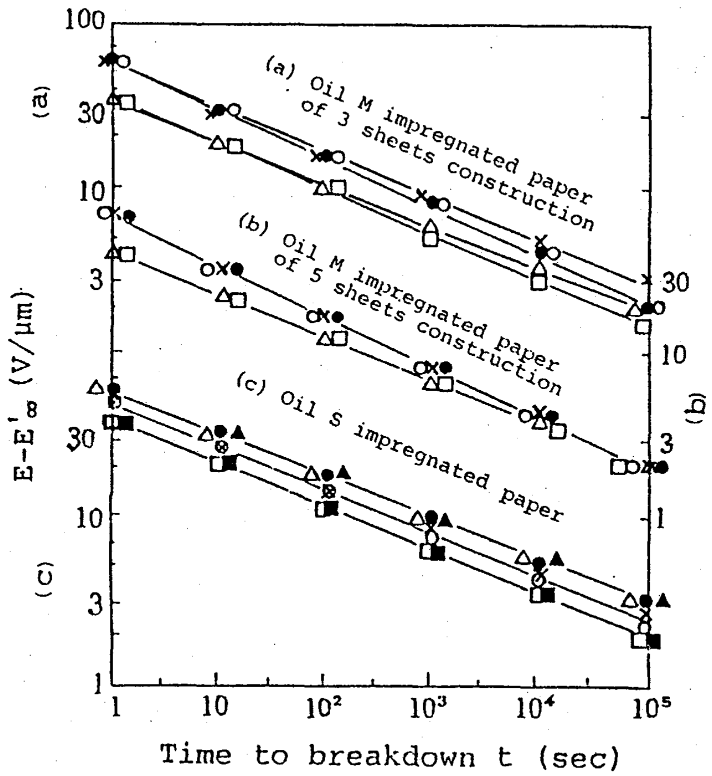

Fig.11 Relation between $E-E'_{\infty}$ and time to breakdown

Where E_{s1} and ν are constants determined by the dielectric.
Appropriate determination of E'_∞ through the actual measurement of the short time region V−T characteristics of each oil impregnated paper (Fig. 3 and 4) gives the relation between $(E-E'_\infty)$ and t which is shown as a line on the graph of log−log scale as shown in Fig. 8 and 11, proving correctness of the equation (14). The E'_∞ values thus obtained are shown in Table 4. If E'_∞ of the oil M impregnated paper assumed to be 100%, E'_∞ of the oil S impregnated paper is 106%, slightly higher than the former. However, in Table 4 all large ratios of (Q)/(N) are those calculated with the predictors of oil M impregnated paper, and the average of only the actual measurements in oil S impregnated paper is 104%.
It can be, therefore, considered that E'_∞ of some types of insulating oil is of almost no difference. Fig. 8 shows the average of $(E-E'_\infty)$ of each sheet number of oil M impregnated paper and the average of $(E-E'_\infty)$ of oil S impregnated paper.
With these values, the following relations are obtained.

(i) Oil M impregnated paper: $E = E'_\infty + E_{s1}t^{-\nu}$

$$=E'_\infty + 52t^{-0.28} \quad \cdots\cdots (15)$$

(ii) Oil S impregnated paper: $E = E'_\infty + 48t^{-0.26}$ $\cdots\cdots$ (16)

In the equations (15) and (16), ν is almost constant, and 0.26 − 0.28 regardless of types of insulating oil. In these equations, E_{s1} is the value of $(E-E'_\infty)$ at t = 1 second.
Fig. 12 shows relation between E'_∞ and insulation thickness ℓ, indicating similar relation between the continuous voltage up ac breakdown voltage stress are ℓ, which is shown in the separate report[5], and is given by the following equations.

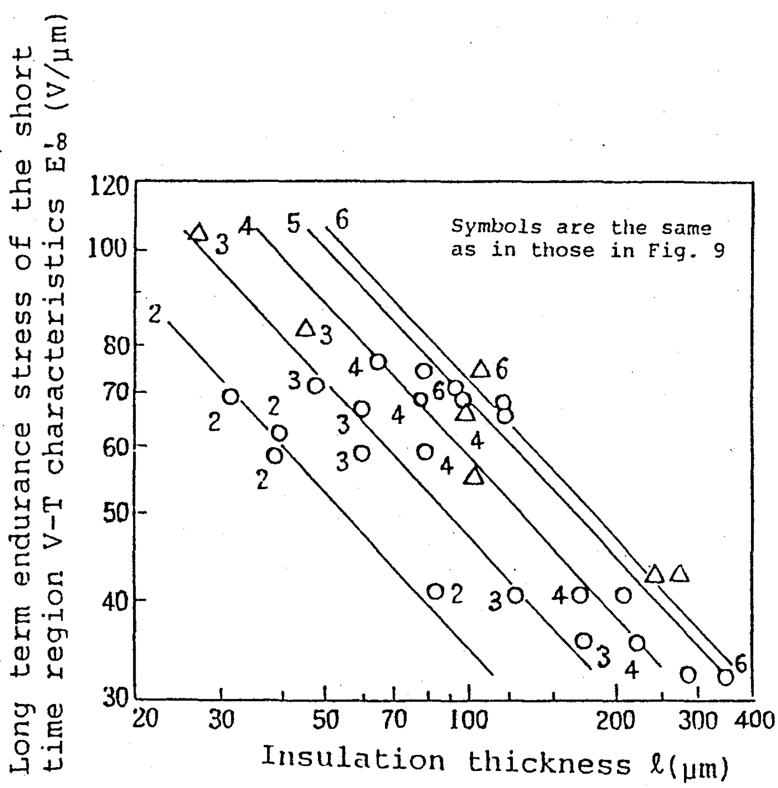

Fig.12 Relation between the long term endurance stress of the short time region V−T characteristics and the insulation thickness

(i) Oil M impregnated paper: $E'_{\infty} = E'_{\infty 1}(n-1.5)^{\alpha'}\ell^{-\beta'}$
$= 680(n-1.5)^{0.45}\ell^{-0.63}$ ……………………………(17)

(ii) Oil S impregnated paper: $E'_{\infty} = 720(n-1.5)^{0.45}\ell^{-0.63}$ ……………………………(18)

Subsequently, the short time region V−T characteristics of oil impregnated paper made of n sheet number of the insulating paper with ℓ_1 thickness is obtained by substituting equations (17) and (18) into (15) and (16), as shown below.

(i) Oil M impregnated paper : $E = E'_{\infty 1}(n-1.5)^{\alpha'}\ell^{-\beta'} + E_{a1}t^{-\nu}$
$= 680(n-1.5)^{0.45}\ell^{-0.63} + 52t^{-0.28}$ ……………………………(19)

(ii) Oil S impregnated paper: $E = 720(n-1.5)^{0.45}\ell^{-0.63} + 48t^{-0.26}$ ……………………(20)

7. Short time ac endurance stress deribed from breakdown voltage of insulating paper

Since the short time region V−T characteristics is considered to be caused by breakdown at the max. electric field part of the surface of the conducting particle included in the insulating paper, the average voltage stress E, when max. electric field E_m at this part is the dielectric breakdown voltage stress E_{lb} of the insulating paper, is understood to be the long term endurance stress E'_{∞}. For simple estimation, consuming that the conductive particle is a revolving ellipse with a radius in the electric field direction a, and a radius in the right angle direction b, and $a = 1.5\ell_1 << b$, E_m/E is given by Salvage[6] as shown in Fig. 13.

The result which gives the relation between

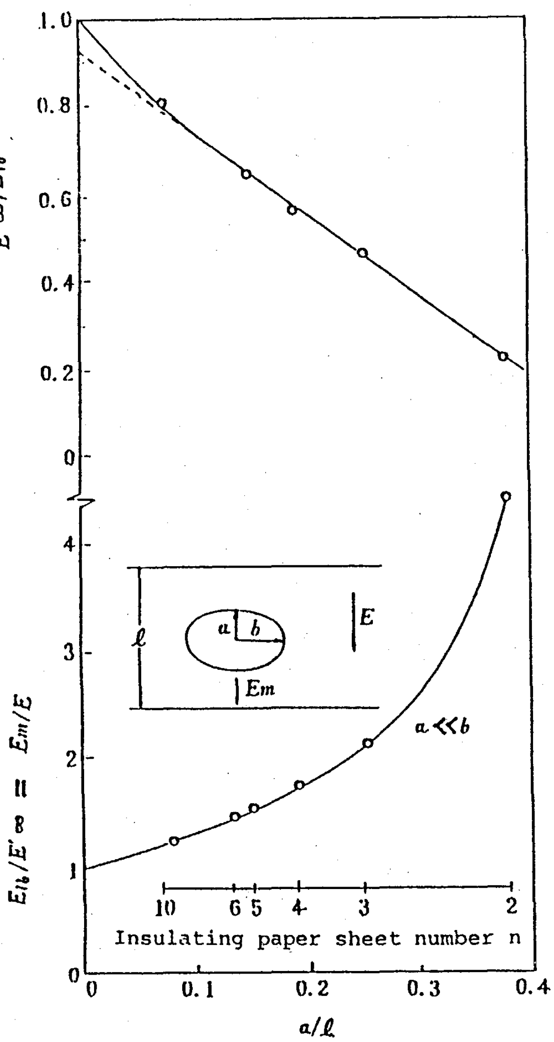

Fig.13 Relation between the insulating paper sheet number and long term endurance stress of the short time region V−T aharacteristics, in case conductive particles are included in the paper

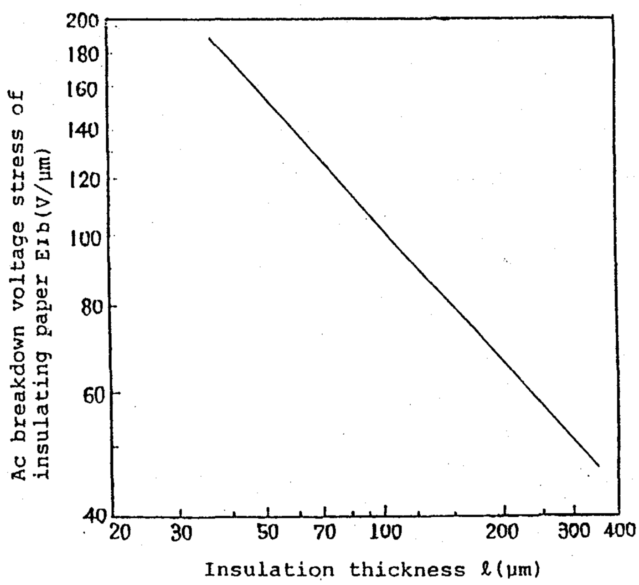

Fig.14 Relation between ac breakdown voltage stress and the insulation thickness of the oil impregnated paper, determining the long term endurance stress of the short time region V−T characteristics of oil impregnated paper

Table 6 Relation between long term endurance stress of the short time region V−T characteristics E'_∞ and dielectric breakdown voltage stress E_{Ib}, and sheet number of oil M impregnated paper

paper sheet numbers n	ℓ =50μm		ℓ =100μm		ℓ =200μm	
	E'_∞	E_{Ib}	E'_∞	E_{Ib}	E'_∞	E_{Ib}
2枚	53V/μm	236V/μm	35V/μm	156V/μm	22V/μm	97.9V/μm
3	72	154	47	101	30	64.2
4	90	158	60	105	38	66.5
5	104	161	69	107	44	68.2
6	110	161	73.5	107	46.5	67.9
Average for 3~6 sheet	−	159	−	105	−	66.7

E'_∞/E_{Ib} and n is shown as a line at n = 2−6 in Fig.13 and is obtained by the following equation.

$E'_\infty/E_{Ib} = 0.92-1.8a/\ell = 0.92-1.8(1.5\ell_1/2n\ell_1)$

$= 0.92-1.35/n$ ··(21)

With oil M impregnated paper, as an example, E_{Ib} is obtained with E'_∞ in Fig. 12 in case of n = 2, 3, 4, 5 and 6, and insulation thickness ℓ = 50, 100 and 200μm. It is shown in Table 6, which is almost identical with E_{Ib} in ℓ = constant and n = 3−6.

The relation between E_{Ib} and ℓ is shown as a line in Fig. 14, and the following equation is obtained.

$E_{Ib} = 1880\ \ell^{-0.63}$ ··(22)

The long term endurance stress E'_∞ of the short time region V−T characteristics of oil M impregnated paper is obtained with equations (21) and (22) as the following equations.

$E'_\infty = (0.92-1.35/n)\ E_{Ib}$ ··(23)

$= (1730-2540/n)\ \ell^{-0.63}$ ··(24)

In comparing E'_∞ obtained by these equations with those obtained by the equation (17), the difference is within 10%.

In case of oil S impregnated paper, the following equations are obtained, showing correspondence with E'_∞ given by the equation (18).

$E_{Ib} = 2{,}000\ \ell^{-0.63}$ ··(25)

$E'_\infty = (1{,}840-2{,}700/n)\ \ell^{-0.63}$ ···································(26)

In order to observe influence of the insulating paper density to E'_∞, specimens B and C of the same insulation construction of oil M impregnated paper capacitor in Table 3 were compared. E'_∞ of C specimen with lower density (d = 0.90g/cm³) is 88−100% of B specimen (d = 1.17g/cm³), showing E'_∞ is larger in higher density paper, as is contrary to the case in E_∞.

8. X−Y plotter display of V−T characteristics of the oil impregnated paper

As stated above, the long time region V−T characteristics of oil impregnated paper with oil M and oil S are described by the equations (6) and (7), respectively. The short time region V−T characteristics are described by the equations (19) and (20), respectively.

With these equations, the long time and short time region V−T characteristics of oil impregnated paper made of optional sheet number (n) of optional insulating paper thickness (ℓ_1 μm) can be plotted on the X−Y plotter, the longer part of V−T characteristics of the short time region V−T characteristics at the intersection of the two V−T characteristics and the shorter part of the long time region V−T characteristics are eliminated, which do not appear in actual mesurements.

With this program, examples of V−T characteristics are printed on the X−Y plotter as shown below.

(1) Influence of insulating paper number

Fig. 15 shows the V−T characteristics of mineral oil impregnated paper with the paper thickness 20μm and the sheet number 2, 3, 5 and 7. In the short time region, the fewer is the sheet number, the greater is the influence of the weak point of the insulating paper and the lower is the breakdown voltage stress.

Whereas in the long time region, the thinner is the total insulation thickness, the higher is the breakdown voltage stress, that is, the fewer is the sheet number, the higher is the breakdown voltage stress. Also in the short time region, the more is the sheet number, the less is the influence of the weak point of the insulating paper, showing greater influence of the total insulation thickness, thus the breakdown voltage stress decreases when the sheet numbers is 5 or more.

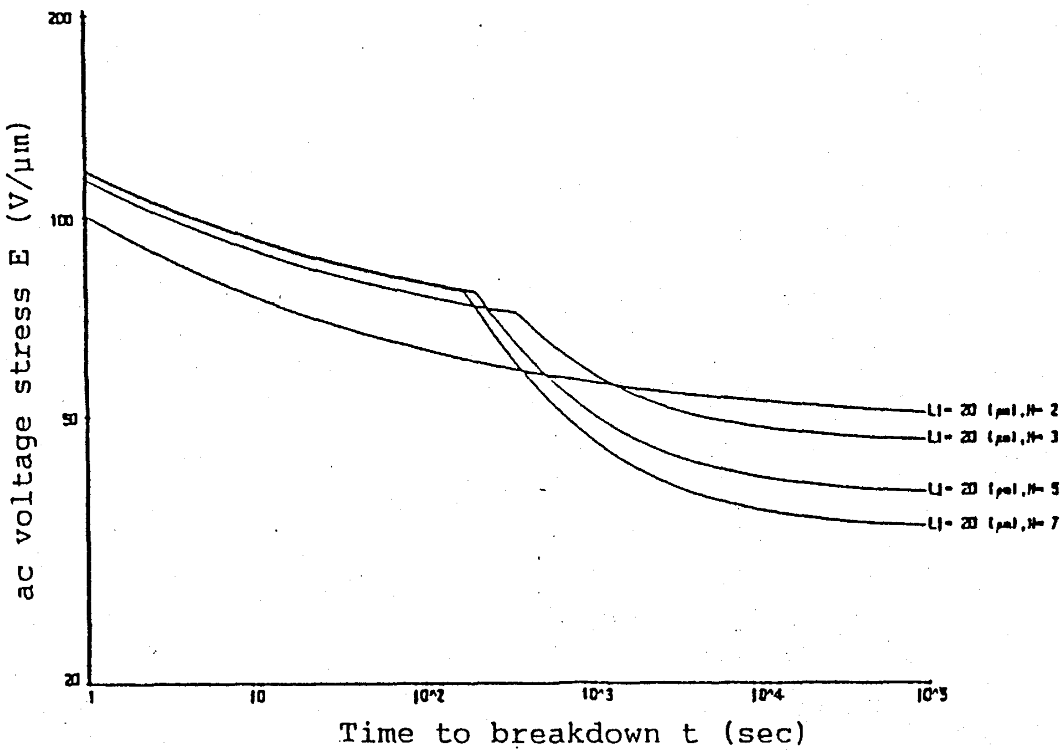

Fig.15 Influence of insulating paper sheet number on V−T characteristics of mineral oil impregnated paper

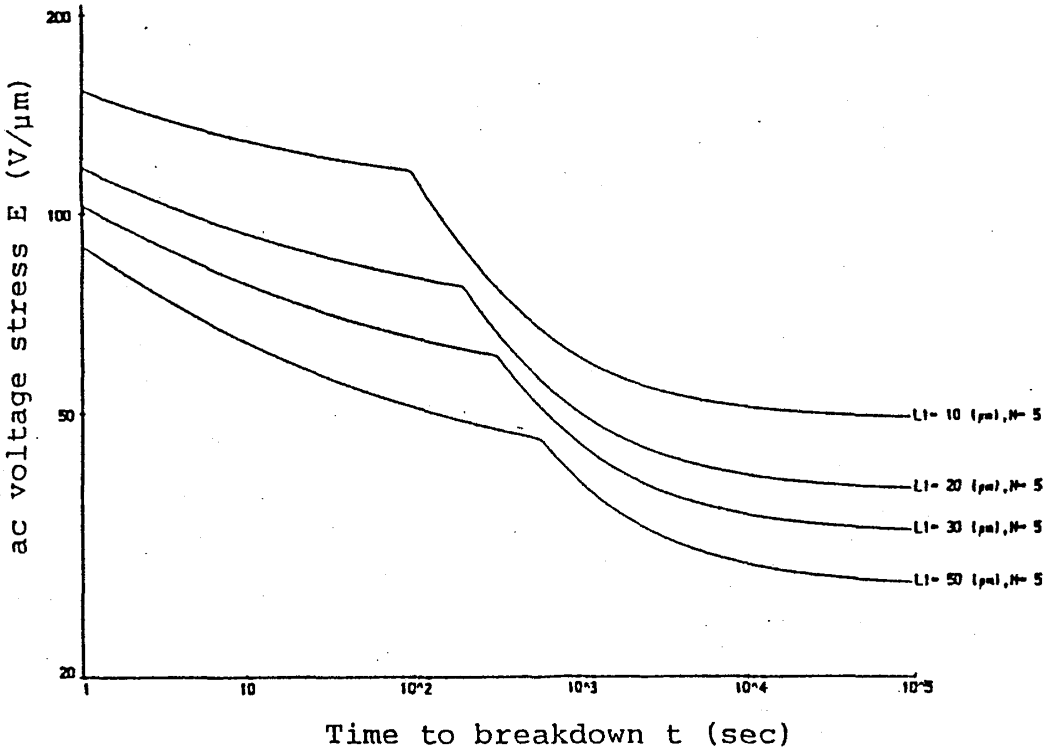

Fig.16　Influence of insulating paper thicknes on V—T charac teristics of mineral oil impregnated paper

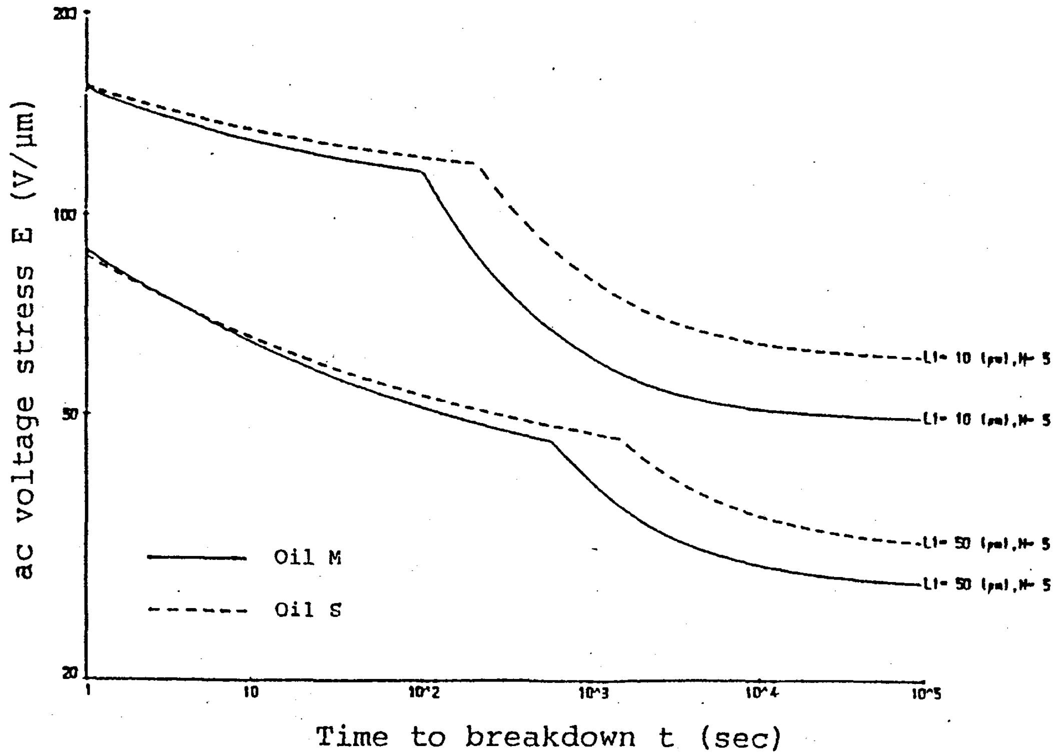

Fig.17　Influence of insulating oil on V—T characteristics of oil impregnated paper

(2) Influence of insulating paper thickness
Fig. 16 shows the V−T characteristics of mineral oil impregnated paper of 5 sheets of the insulation thickness 10, 20, 30 and 50 μm. Since 5 sheets of the insulating paper decreases influence of the weak point of the insulating paper as stated above, in both short time and long time regions, the thinner is the insulating paper, the higher is the breakdown voltage stress.
(3) Influence of impregnated insulating oil
Fig. 17 shows the V−T characteristics of mineral oil and alkylnaphthalene impregnated paper of 5 sheets imulating paper of thickness 10 μm and 50 μm. In the short time region, breakdown of oil impregnated paper occurs directly due to breakdown of the insulating paper, showing almost no difference in the types of insulating oil. Whereas, in the long time region, breakdown of oil impregnated paper starts from partial breakdown of the insulating oil and proceeds to breakdown of the whole oil impregnated paper, showing greater influence of insulating oil. Accordingly, the insulating paper impregnated with alkylnaphthalene with higher gas absorptivity than mineral oil shows quite higher V−T characteristics.

9. Conclusion

The mechanism of the V−T characteristics in imposing ac voltage to the insulating paper impregnated with mineral oil and alkylnaphthalene was eludicated, and influence of the insulating paper construction was made clear. With the results, the computer program was created which draw on the X−Y plotter the V−T characteristics of mineral oil and alkylnaphthalene impregnated paper with optional insulation construction. This study simplified obtaining methods of V−T characteristics of impregnated paper which used to take a lot of specimens and long time in processing. We hope that these results are broadly employed as insulation data on oil impregnated power apparatus such as power capacitors, transformers and cables.

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