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FUJI METAL OXIDE SURGE ARRESTER

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1 FOREWORD

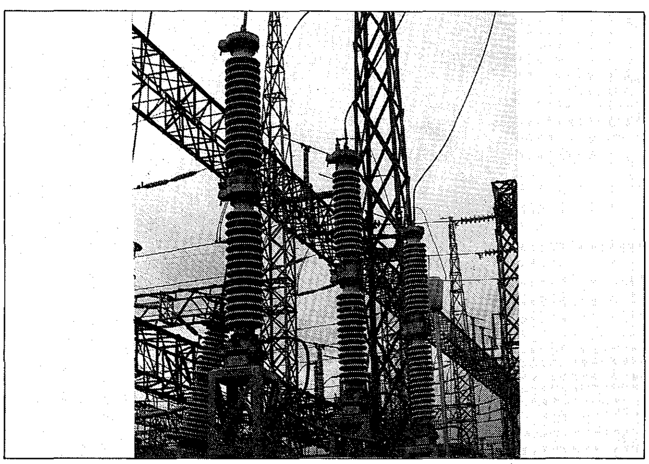
Recently, metal oxide arresters without series gap have got a superior position than the conventional type arresters for protecting the equipment in a power system against various overvoltages and lightning and switching surges.

To meet these needs, Fuji Electric has developed high performance zinc oxide elements with the rate-earth element praseodymium added to a zinc oxide and has completed a series of 3.3 to 187 kV system metal oxide surge arresters. This series is outlined here.

Fuji Electric began development of arresters in 1952 by introducing technology from Siemens of West Germany, that has the best record in the world in the field of arresters, and has accumulated research and development and produced numerous arrester over the 34 years since then.

On the other hand, attention has been focussed on the superior non-Ohmic voltage-current characteristics and current withstand strength of the zinc oxide element and research on zinc oxide elements was initiated in 1972. As a result, in 1974, "the Fuji Zetrap" of AC 440 V and less was developed and low voltage circuit surge absorber mass production technology was established. In 1979, an element for 3.3 to 6.6 kV distribution system and, at the same time, a 10 kA element for cable sheath protection were developed and many units were delivered. In 1983, we succeeded in developing a high performance power element and an electric railway DC element which compositions and production conditions were considerably improved. Besides test's specified in the new Japanese metal oxide arrester standard JEC-217, various practical tests, including long-term charging test with actual equipment, were performed and their superior performance was confirmed. A perfect production facility and quality control organization was also established.

Fig. 1 Application example of rated voltage 196 kV Fuji metal oxide surge arrester



The Fuji Electric metal oxide surge arresters serialized this time are based on Fuji Electric's zinc oxide element technology and arrester development technology and experience accumulated over many years.

Application examples of the rated voltage 196 kV Fuji metal oxide surge arrester are shown in Fig. 1.

2 OPERATING PRINCIPLE OF FUJI METAL OXIDE SURGE ARRESTER

The zinc oxide element has a zinc oxide (ZnO) as its main component and is a ceramic with praseodymium oxide (Pr_6O_{11}), which is a feature of Fuji ZnO element, and cobalt oxide (Co_3O_4) added to this and sintered. The microstructure of the element is shown in Fig. 2. The figure shows that the ZnO ceramics consists of ZnO grains of 10~ 20 μm and a intergranular phase. This composit structure is the main origin why the element has the non-Ohmic properties origin.

Some additive components like Co_3O_4 are dissolving in ZnO grains. On the other hand praseodymium oxide forms the intergranular phase. Fig. 2 was photographed with

Fig. 2 Microstructure of zinc oxide element

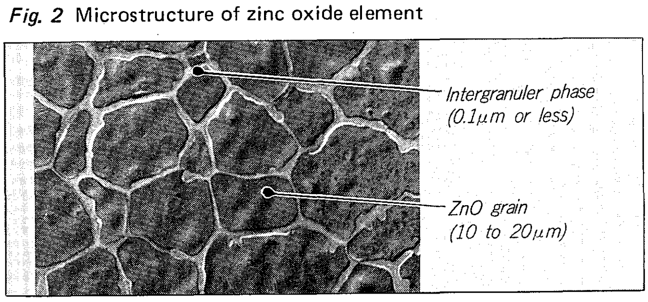


Fig. 3 Voltage-current characteristics of ZnO element

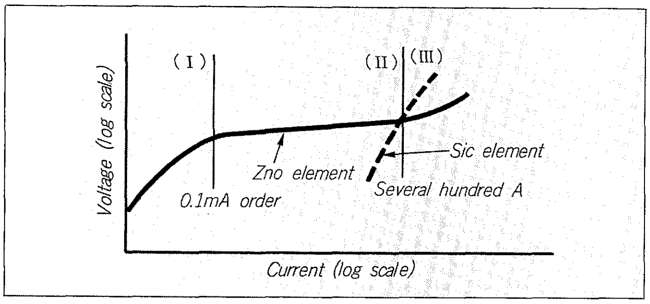


Fig. 4 Outside shape of ZnO element

ascanning electron microscope (SEM). The thickness of the intergranular phase is estimated to be 0.1 μm or less.

The zinc oxide crystal is an n-type semiconductor which normally shows low Ohmic resistivity of about 1 Ω·cm. The crystal itself has a ohmic characteristic.

Generally, the voltage-current characteristics is approximated by,

$I = kV^{\alpha}$ (I: Current, V Voltage, k, α: Constant)

and the curve is devided into (I) Prepreakdown region, (II) Breakdown region, and (III) Upturn region.

When applied voltage is low, electrons flow over the Schottky barrier by thermal activation. As this case shows small value ($\alpha = 0.5 \sim 1$), this current region is called prebreakdown region. If the voltage is increased beyond the threshold value, the high electric field of the reversely biased barrier causes tunneling of electrons captured by traps in the Pr_2O_3 layer resulting in rapid current rise. This region is called breakdown region which has high value of more than 40. When the voltage is additionally increased until the current reaches up to several tens of kilo amperes, the voltage across ZnO grain itself grows larger than that of the Schottky barrier and non-Ohmicity becomes smaller reaching finally to unity. Because voltage-current curve by this process upturns, this region is called upturn region.

Since both axes of voltage-current characteristics of Fig. 3 use a logarithmic scale, the nonlinearity appears to be small, but if this is changed to a proportional scale, it can be seen that a nonlinear performance is shown.

When compared with the SiC element shown by the dotted line in Fig. 3, the excellent non-linearity of the zinc oxide element can be seen.

The outside shape of the zinc oxide element is shown in Fig. 4.

3 FEATURES

The features of the Fuji metal oxide surge arrester are described below.

3.1 Large electrostatic capacitance

(1) For multilayer stacking, the stray capacitance to ground has little effect and a condenser for equalizing the voltage distribution is unnecessary.

(2) Since the voltage distribution among the elements is uniform, deterioration of the element during long term operation is reduced.

Metal oxide element type are devided into two groups by additive components.

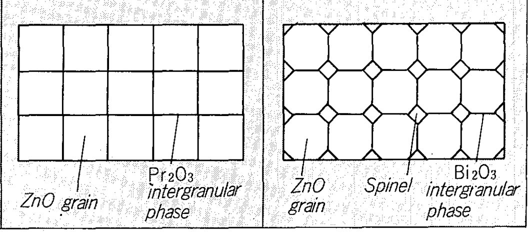
One is the element which main additive component is bismuth oxide, another is the element which main additive component is rare earth oxide praseodymium. Regarding the micro structure of the elements with bismuth as the main additive component, it is formed by three phase system. They are low resistance ZnO grains, the intergranular layer of bismuth (Bi_2O_3) and the spinel ($Zn_7Sb_2O_{12}$) structure that governs to characteristics at sintering. On the other hand, since elements with the rare earth as the main additive component are formed by two phase system which consists of ZnO crystal grains and praseodymium oxide (Pr_2O_3) intergramular surrounding these grains, the effective area of the intergranular layer that generates the nonlinearity is large and the effective dielectric constant is larger than that of the three-phase system element. Therefore, the electrostatic capacitance becomes large. The electrostatic capacitance (capacitance per intergranular) C_0 of an element can be expressed by the following equation:

$$C_0 = \frac{1}{2} \cdot \frac{d}{t} \sqrt{\frac{q \cdot \epsilon s \cdot Nd}{2\phi}} \cdot S$$

d: Grain diameter — S: Electrode area
ϕ: Barrier height — q: Electron charge
t: Element thickness — ϵs: Dielectric constant of ZnO crystal
Nd: Donor density

Fig. 5 Comparison of microstructure models

System	Rare earth	Bismuth
Main component	ZnO	ZnO
Additive	Pr_6O_{11}, Co_3O_4, K_2CO_3, Cr_2O_3	Bi_2O_3, CoO, MnO, Sb_2O_3, Cr_2O_3
Micro-structure	Two-phase system ZnO grain and Pr_2O_3 intergranular layer	Three-phase system ZnO grain spinel ($Zn_7Sb_2O_{12}$) and Bi_2O_3 intergranular layer



The two-phase system features a large donor density and large effective area, etc. and the electrostatic capacitance is large.

An example of comparison of the microstructure models is shown in Fig. 5.

3.2 Low residual voltage characteristic

Since the voltage-current characteristic shows excellent nonlinearity, the residual voltage is low. Especially, since the effective area of the intergranular surface is large, the nonlinearity at the high current region is improved.

The V-I characteristic is shown in Fig. 6.

3.3 Excellent steep wave response characteristic

Since a unique Fuji Electric additive is used, the response to steep waves is excellent and when the steep wave front time is 1 μs at a 10 kA discharge current, the voltage rise is suppressed to 4% of that at 8 μs. Therefore,

Fig. 6 Voltage-current characteristic (rated voltage 2.8 kV)

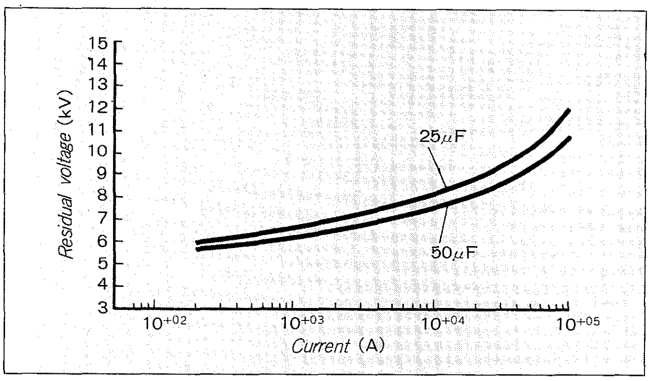


Fig. 7 Steep wave response characteristic (discharge current 10 kA)

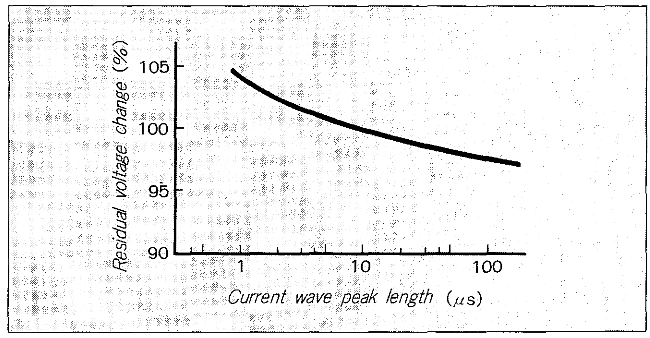


Table 1 Power distribution surge arrester series and specifications

Model			BVA594··············					BVA598··············				
			··········kA				···LB	··········kA				···LB
Item			10A1P	1FA1P	00A1P	0FA1P	0FA1P	10A1P	1FA1P	00A1P	0FA1P	0FA1P
Rated voltage (kV)			4.2					8.4				
Nominal discharge current (kA)			5				10	5				10
Applicable zone			Indoors		Outdoors		Indoors Outdoors	Indoors		Outdoors		Indoors Outdoors
Pressure relief device (31.5 kA)			NO	YES	NO	YES	YES	NO	YES	NO	YES	YES
Reference voltage (kV)		Specified value	7.1 or more					14.3 or more				
		Management value	8.0~9.4					16.0~18.8				
Residual voltage (kVp) or less	2.5 kA	Specified value	–				–	–				–
		Management value	15				–	30				–
	5.0 kA	Specified value	17				–	33				–
		Management value	13~16				16	26~31				31
	10 kA	Specified value	–				17	–				33
		Management value	17				14~17	33				28~33
	20 kA	Specified value	–				–	–				–
		Management value	–				18	–				35
Current withstand strength	Lightning impulse (4/10 μs)		65 kA (two times)									
	Square wave (2 ms)		400A (20 times)									
Operating duty	Lightning impulse current (kA)		5				10	5				10
	Switching surge static capacitance (μF)		15				25	15				25
Withstand voltage (kV)	Power frequency		16 (dry 1 min, wet 10 secs)					22 (dry 1 min. wet 10 secs)				
	Lightning impulse		45					60				
Weight (kg)			2	5	2	5	5	3	7.5	3	7.5	7.5
Applicable standard			JEC-217 (1984)									

even for lightning near the substation, lightning near the inlet of the gas insulated switchgear (GIS), etc., the rise of the residual voltage can be suppressed. Moreover, since V-*t* characteristic of the insulation strength for GIS is ralatively flat, protection against steep waves is emphasized. However, it is said that the Fuji metal oxide surge arrester, which has an excellent steep wave response characteristic, is perfect for GIS use. The response characteristic is shown in Fig. 7.

3.4 Long life element

To optimize the composition and production conditions of the element developed this time, the life characteristic was improved substantially. The test result is shown in Fig. 8. A life of 100 years or more can be expected at an applied voltage ratio 95%.

4. SPECIFICATIONS

The ratings and specifications table for a rated voltage

Fig. 8 Arrhenius' plot of result of electrical life test

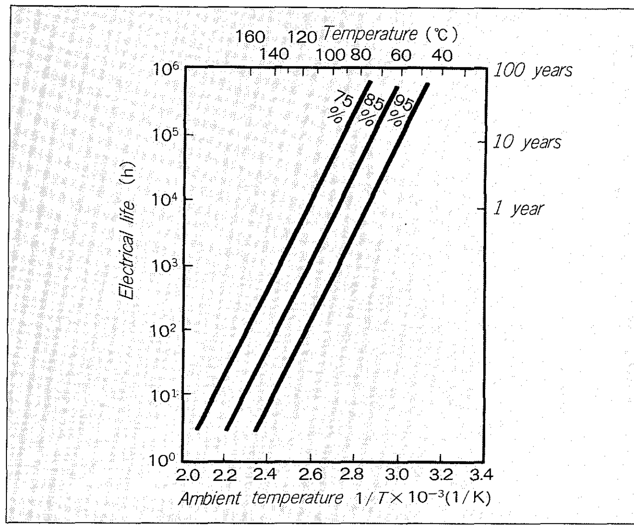


Table 2 Power use surge arrester series and specifications

Model		System condition					Withstand voltage (kV)		Residual voltage (kV) (or less)								Reference voltage (kV) (or more)				Current withstand strength		
									Lightning impulse				Steep wave lightning impulse		Switching impulse								
									At 10 kA		At 5 kA												
Standard type	Pollution withstand type Hot line washing	Ground system	Nominal voltage (kV)	Maximum voltage (kV)	Insulation class	Rated voltage (kV)	Power frequency	Lightning impulse	Guaranteed value	Management value	Guaranteed value	Management value	Guaranteed value	Management value	Guaranteed value	Management value	Guaranteed value	Management value	Maximum continuous operating voltage (kV)	Switching surge operating duty static capacitance (μF)	Lightning impulse (kA)	Square wave (A)	Pressure-refief, current (kA)
			11	11.5	10A	14	28	90	47	36~41.5	43	38.5 or less	52	44 or less	50	34.5 or less	19.8	20~23.5	11.5/√3				
			22	23	20A	28	50	150	94	72~83	85	77	103	88	90	69	39.6	40~47	23/√3				
BVH (G)	BVH		33	34.5	30A	42	70	200	140	108~125	128	116	154	132	120	104	59.4	60~70.5	34.5/√3				
			66	69	60	70	140	350	224	180~208	203	193	246	220	200	173	99	100~118	69/√3				
-LB	-LB	Not effective				84			269	216~249	244	231	296	264	240	207	119	120~141		25	100	400	31.5
			77	80.5	70	98	160	400	314	252~291	284	270	345	308	281	242	139	140~165	80.5/√3				
-0	-3~5		154	161	80	112	185	450	358	288~332	325	308	394	352	320	276	158	160~188	92/√3				
					100	126	230	550	403	324~374	365	347	443	396	361	311	178	180~212	103.5/√3				
			110	115	100	140	230	550	448	360~415	406	385	493	440	401	345	198	200~235	115/√3				
			66	69	60	84	140	350	269	207~237	244	219	296	252	240	206	119	120~141	69/√3				
BVH (G)	BVH	Not effective	77	80.5	70	98	160	400	314	242~277	284	256	345	294	281	240	139	140~165	80.5/√3				
-LC	-LC		110	115	100	140	230	550	448	345~395	406	365	493	420	401	343	198	200~235	115/√3	50	100	800	31.5
		Effective	187	196	140	182	325	750	582	449~514	528	475	640	546	522	445	232	260~306	195.5/√3				
-0	-3	Not effective	154	161	140	196	325	750	627	483~555	568	511	690	588	561	480	277	280~329	161/√3				

Fig. 9 Porcelain type surge arrester structure

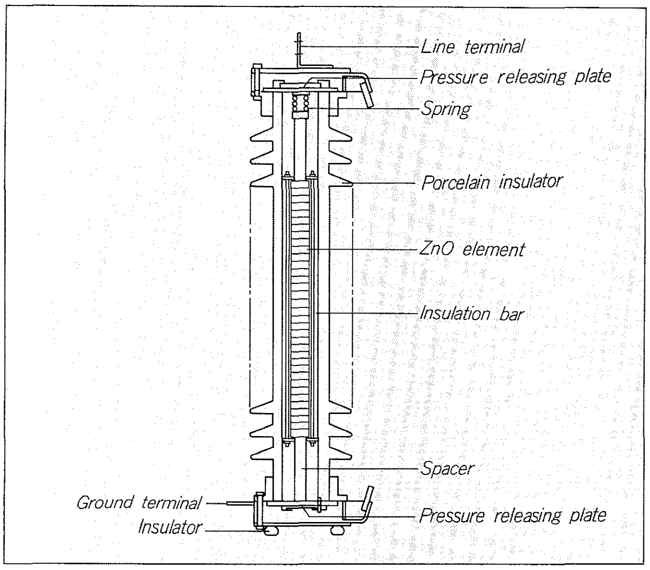
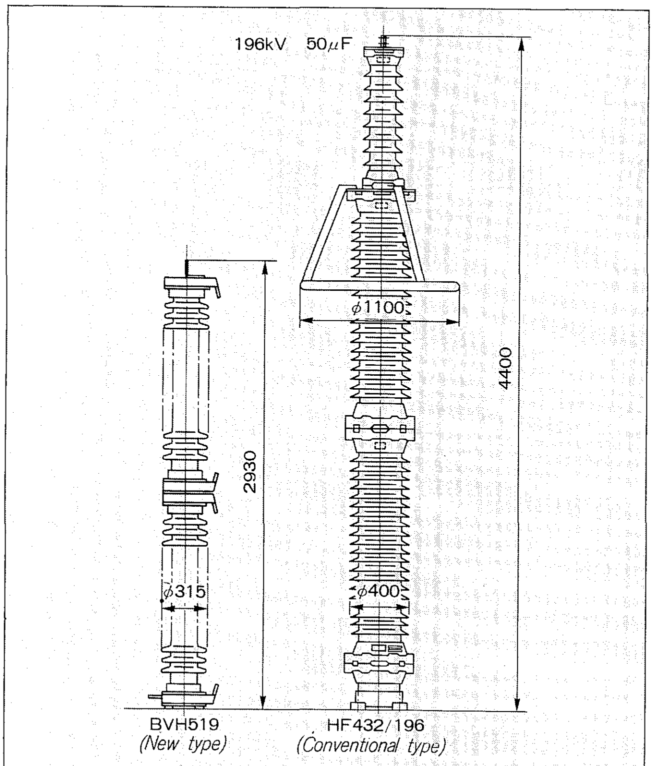


Fig. 10 Comparison of new and conventional porcelain type surge arresters



4.2 to 8.4 kV power distribution use surge arrester is shown in Table 1 and the ratings and specifications table for a rated voltage 14 to 196 kV power use surge arrester is shown in Table 2.

5 CONSTRUCTION

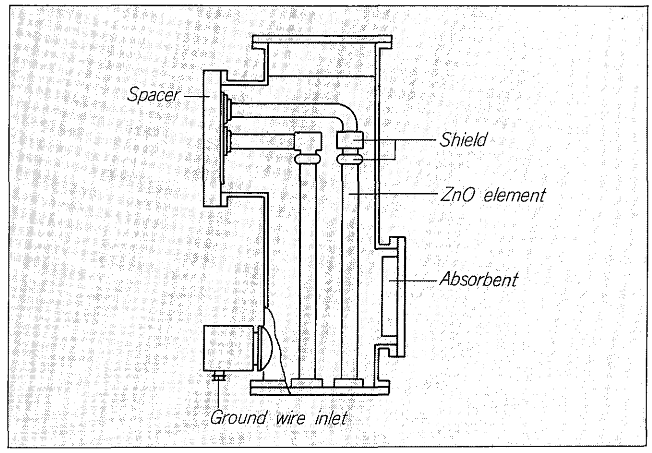
5.1 Porcelain type arrester

A example of the cross section construction is shown in Fig. 9. The specified number of ZnO elements are stacked and the internal unit tightened by an insulation bar is pressed forcefully by a spring and is housed in an porcelain insulator. Atmospheric pressure nitrogen gas is sealed in the porcelain insulator. Then, pressure releasing plate is installed to both ends of the porcelain insulator to prevent it from exploding and shattering.

Since the ground terminals are insulated from ground by a insulator, discharge current measuring equipment and surge counter and deterioration diagnosis resistance leakage current measuring equipment can be connected.

The conventional and new Fuji Electric arresters are compared in Fig. 10. The new Type BVH5 is 66% lower and 55% lighter.

Fig. 11 Structure of tank type surge arrester for GIS



5.2 Tank type surge arrester for GIS

The cross section structure is shown in Fig. 11. The basic composition is the same as the porcelain type. An electric field dampening shield is installed at the head of the ZnO element. Up to rated voltages of 196 kV, three-phase together and the sealed gas is 5 kgf/cm^2 SF_6 gas. The gas management system is the same as the GIS.

6 TEST RESULTS

The model test items of JEC-217 and various practical tests for surge arresters were performed. All the tests confirmed the excellent performance. The tests are outlined in Table 3.

7 CONCLUSION

The principles, construction, series, and performances of the metal oxide surge arrester without a series gap developed by Fuji Electric were described. Since this surge arrester uses a unique high performance zinc oxide element, is has such features as;

(1) Low residual voltage
(2) Excellent steep wave response
(3) Suitable for multi-lightning duty

Table 3 Test certification items summary table

No.	Test item	Contents	Porcelain type	Tank type
1	Construction inspection	All complete products	○	○
2	Insulation resistance test	All complete products	○	○
3	Continuous current test	All completed products	○	○
4	Reference voltage test	All completed products	○	○
5	Residual voltage test	Performed by 14 kV unit	○	○
6	Lightning surge operation duty test	Performed by 14 kV unit	○	–
7	Switching surge operation duty test	Performed at 14 kV unit	○	–
8	Stability evaluation test	Performed at 2.8 kV unit	Element	–
9	Contamination and hot line washing test	Performed for 42 to 196 kV	○	–
10	Pressure-relief test	Performed with 0.3 kA and 31.5 kA class	○	–
11	Deterioration withstand test	Air tightness test and water immersion test	○	–
12	Power frequency withstand voltage test	Performed by drying and pouring water for porcelain insulator only	○	–
13	Lightning impulse withstand voltage test	Performed by drying and pouring water for porcelain insulator	○	–
14	Partial discharge test	Performed for 14 to 196 kV	○	○
15	Corona test	Performed for 84 to 196 kV	○	○
16	Environment test	Performed at –35 to +60°C, 80% humidity	○	–
17	Earthquake withstand test	0.3G, 3 sine waves applied with and without frame	○	–
18	Shipping test	Performed by running 1,000 km	○	○
19	Gas tightness test	Gas leakage measured by integration method	–	○
20	Pressure withstand test	Performed according to pressure container construction standard article 143 item 2	–	○
21	Freezing test	After pouring water over the entire surface, frozen at –35°C	○	–
22	Pressure releasing plate fatigue test	Performed 15,000 times at ΔP = 0.3 kg/cm	○	–
23	Lightning impulse V-I characteristic test	Residual voltage at 40 to 100 kA measured	Element	–
24	Square wave impulse current test	2 ms waveform applied 20 times	Element	–
25	Long term charging test	Accelerated deterioration performed with 196 kV/98 kV unit	○	○
26	Electrical life test	Evaluation by Arrhenius' plot	Element	–
27	Lightning impulse continuous impression test	Characteristic checked after 100 kA applied 10 times	Element	–
28	Voltage dictribution measurement	Element distribution voltage measured with actual large model	○	○
29	Decomposed gas withstand test	Performed with and without adsorbent	–	○

< Note > Nos. 1 to 13 are type test items.

(4) Excellent contamination resistance
(5) Long life element

We are confident that it matches the desires of users. Especially, it is considered perfect for application to GIS and for equipment interior use.

In the future, we want to conduct research and development on an effective application method (ideal layout) that includes high performance zinc oxide elements and equipment interior use toward reducing the insulation level of systems.

Finally, the authors wish to thank all those concerned for their guidance.