LIGHTNING ARRESTER PERFORMANCES ASSOCIATED WITH THE SWITCHING OPERATION IN A 275 KV SUBSTATION

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1. Introduction

One of the extra-high voltage systems in Central Japan is just located around the City of Nagoya. The main part of this system is the form of a round arch, its radius being about 25 km, its length about 120 km, and is operated under the voltage of 275 kv to receive a bulk of electric power generated by large steam-plants and hydroelectric stations, to deliver the power to the industrial manufacturing district around Nagoya and to keep in contact with the adjacent western extra-high voltage system around Osaka. This central extra-high voltage system is effectively grounded and the transformer insulation is reduced by one step, taking a voltage of 1,050 kv as basic impulse insulation level (BIL). Before the reduced BIL transformers were universally adopted, in most cases, switching surges had been the matter of little concern since their magnitudes were sufficiently below the insulation strength of the windings. Under the reduced insulation level, however, normal switching surges become a vital nuisance and lightning arresters must be universally relied upon for the complete system protection. To provide with adequate switching surge protection, both the arrester sparkover characteristics and the transformer insulation strength against switching surges must be well observed. Both of these quantities will be a function of the shape and magnitude of the switching surge.

In the above mentioned system, it is expected to restrain switching surges by means of lightning arresters. The urgent necessities for the system design and operation forced us to draw up a plan of a field test to inspect the practical performance of the arresters against switching surges. The field test was actually carried out on 19, November 1961.

2. Description of Test Performances

The switching surge test was carried out at Nishi-Nagoya Substation (SS), situated far west of Nagoya. Fig. 1 shows the location of this substation as a key station of the western part of this 275 kv line. At that time, the 275 kv line was terminated at Nishi-Nagoya SS at the extremity of 66 km line extended from Seki Switching Yard (SY). At the Switching Yard the line was drawn out further to the eastern part and also connected with the EHV system in Western Japan. Fig. 2 shows the single-line schematic diagram of the test line and terminal equipments. The 260 kv arresters were connected about 30 meters apart from the terminals of 275 kv main transformer with a three phase capacity of 220 mva. A total number of 22 switching operations were executed with the air

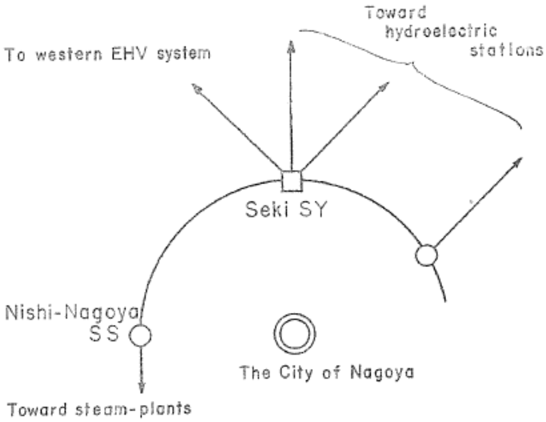

FIG. 1. 275 kv EHV system in Central Japan

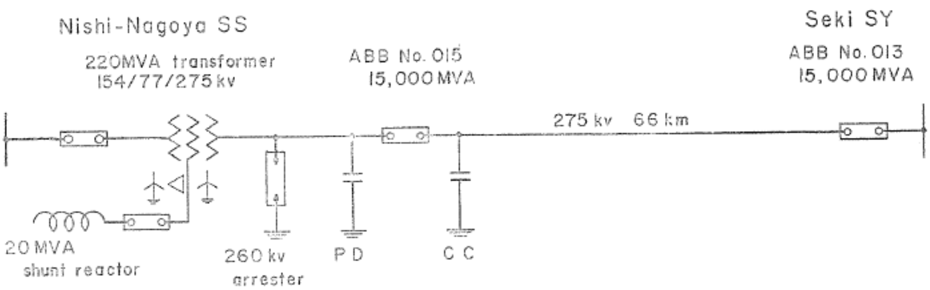

FIG. 2. Single-line schematic diagram of test line and terminal equipments

blast circuit breaker (ABB) No. 015 installed at the end of the line from Seki SY. The 22 operations can be divided and grouped into three separate test series described in the following paragraph.

Test Series I: Energizing and De-energizing the Open Line. With ABB No. 013 at Seki SY opened, ABB No. 015 at Nishi-Nagoya SS energized and de-energized the 66 km unloaded line. The line charging current was supplied from the 220 mva transformer bank excited from 154 kv side as the power source. The test results from No. 18 to No. 22 are shown in Table 1.

Test Series II: Energizing and De-energizing the 220 mva transformer bank. With ABB No. 013 at Seki SY closed, the 220 mva transformer bank was connected to or cleared from the 275 kv line, as the power source, by the operation of ABB No. 015. Both 154 kv and 77 kv windings were left opened. The results of this test series from test No. 1 to No. 12 are shown in Table 1.

Test Series III: Energizing and De-energizing the transformer bank connected with the 20 mva shunt reactor on the 77 kv tertiary winding, the 154 kv secondary winding being kept opened. The results of this test series from test No. 13 to No. 17 are shown in Table 1. During the operation of this test series were produced two actual records of arrester performance.

Three of the cathode-ray oscilloscopes (CRO) were employed during these tests: 12 elements and 6 elements ordinary-speed CRO, loading film with 45 cm

TABLE 1. Analysis of CRO Oscillograms

Test Series	Test No.	Switching Operation of ABB No. 015[1]	Normal Line-to-line Voltage (kv rms)[2]	Cleared Line Current on Phase A (Arms)	Maximum Transient Peak PU to line-to-ground crest voltage					Typical Frequencies Contained in Voltage Transients on 275 kv Side (c/s)
					On 275 kv Terminals of Transformer			On 154 kv Terminal of Trans. Phase A	On 77 kv Terminal of Trans. Phase A	
					Phase A	Phase B	Phase C			
II	1	C	289	—	1.37	1.37	1.07	—	—	—
	2	O	287	7.2	1.13	—	〃	—	—	4500
	3	C	281	—	—	—	—	1.26	1.12	〃
	4	O	〃	6.9	1.07	—	—	—	—	—
	5	〃	〃	7.2	—	—	—	—	—	—
	6	〃	284	7.3	1.33	—	—	1.37	1.10	—
	7	〃	〃	7.5	—	—	—	—	—	2700
	8	CO	—	—	—	—	—	—	1.28	4400
	9	〃	—	—	—	1.67	—	—	—	3700
	10	〃	—	—	1.63	—	1.29	—	—	—
	11	〃	—	—	—	1.63	—	—	—	—
	12	〃	—	—	—	—	—	—	—	—
III	13	C	277	—	—	—	—	—	—	—
	14	O	〃	48	1.69	2.17	1.94 (scale over)	1.53	1.35	2,000;430
	15	C	〃	—	—	—	—	—	—	—
	16	O	〃	48	1.83	2.03	1.61	1.83	1.25	2,000;430
	17	〃	〃	〃	1.87	2.10	2.00	1.84	1.81	〃
I	18	CO	263	—	1.22[3]	1.28	1.67	—	—	420
	19	〃	〃	—	1.48	1.45	1.40	—	—	〃
	20	〃	〃	—	1.11	1.52	1.53	—	—	〃
	21	O	〃	50	—	—	—	—	—	〃
	22	〃	〃	〃	—	—	—	—	—	〃

1) C: Closed, O: Opened, CO: Closed-t-Opened, t: an interval of 12 cycles. (60c/sbase)
2) Line-to-line voltage between phase B and C before each test was carried out.
3) Transient peak voltage just after energizing the line.

length being drived at a speed of about 1.8 m/sec, and 6 elements high-speed CRO, loading with 180 cm roll film drived at a speed of about 20 m/sec. The former two CRO's recorded the line-to-ground voltages on the both terminals of ABB No. 015, the voltages between the ABB terminals, the line currents, the arrester currents of all phases, and the line-to-ground voltages on the 154 kv and 77 kv terminal in one and the same phase. The high-speed CRO recorded only the voltages between ABB terminals. Potential dividers (PD) and Coupling condensers (CC) for carrier current telephony on power lines, which were connected with damping resistances in series, were available for voltage measurement with favourable frequency-responses. The line currents were recorded by the magnetically deflected cathode-ray tubes with the deflection field caused by the secondary current of current transformers. The arrester currents were measured through non-inductive 1 Ω shunt resistances connected in series between arrester lower terminals and grounding mesh.

3. Results Obtained

All the test results are shown in Table 1 which represents analytical data of the CRO's records together with the values of normal line-to-line voltage and phase current.

During test series I and II no arrester operations are observed. In test series I, ABB No. 015 successfully de-energized the unloaded line without restriking and, therefore, without producing any overvoltage, while slightly higher than normal voltage was recorded at the crest of the voltage transient just after energized. The cleared line voltage to ground retained 72-75% of the initial normal voltage even at the period of 1 second later than that of interruption. It is shown that the trapped charge remaining on the cleared line leaks rather slowly over the surface of line insulations. This was recorded at the test No. 21, in which were disconnected the leakage resistances of 10 MΩ normally inserted in parallel to the deflection plates of CRO's.

In Test series II, the transformer bank was de-energized according to the two different conditions. The transformer usually takes a remarkable transient current, the wave form of which is by no means sinusoidal during a period of several seconds after energized. Such a singular current gradually reduces to the ordinary exciting current of a normal steady state of about 7 A with a sinusoidal-wave form. De-energizing operations in test No. 2 and No. 4 to No. 7 were carried out under the steady state exciting current condition and in test No. 8 to No. 12 within the period of singular transient current. Every switching operation was only accompanied with slightly higher transient voltage, which was caused by a current chopping.

In test series III, the violent voltage transient happened to occur during the normal interrupting process without any restriking, as shown in Fig. 3. The transformer, connected with the shunt reactor of 20 mva on the tertiary winding, was supplied with the lagging-phase current up to 48 Arms. The line current on each phase was successively cleared up at the time designated by t_1, t_2 and t_3. The violent transients with a frequency of 430 c/s were found after t_2 and t_3 on the transformer terminals. Their crests reached as high as more than 2 times of the normal line-to-ground voltage. The additional small components with the frequency of 2 kc/s were also found at the early periods just after t_1, t_2 and t_3.

TABLE 2. Arrester Performances

Test Series	Test No.	Operation Phase	Sparkover Voltage to Ground (kv peak)	Frequency of Transient Voltage (c/s)	Crest Current (A)	Discharging Period (ms)	Diameter of the Damaged Hole on Recording Paper Inserted in Series (mm)
III	16	A	415	2,000	111	5.62	1
	17	B	470	〃	83	1.39	pin-hole

These switching overvoltages had played a distinguished role in arrester sparkover as is observed in the test No. 16 and 17. The results of analysis of the arrester sparkover are shown in Table 2. The first arrester sparkover took place on phase A at about 415 kv and the second on phase B at about 470 kv. The arrester current had a crest of 111 A and 83 A respectively, each cleared off within the time of 5.62 and 1.39 msec. Fig. 4 is a copy of the ordinary CRO oscillogram, showing the whole interrupting process in test No. 16. The first

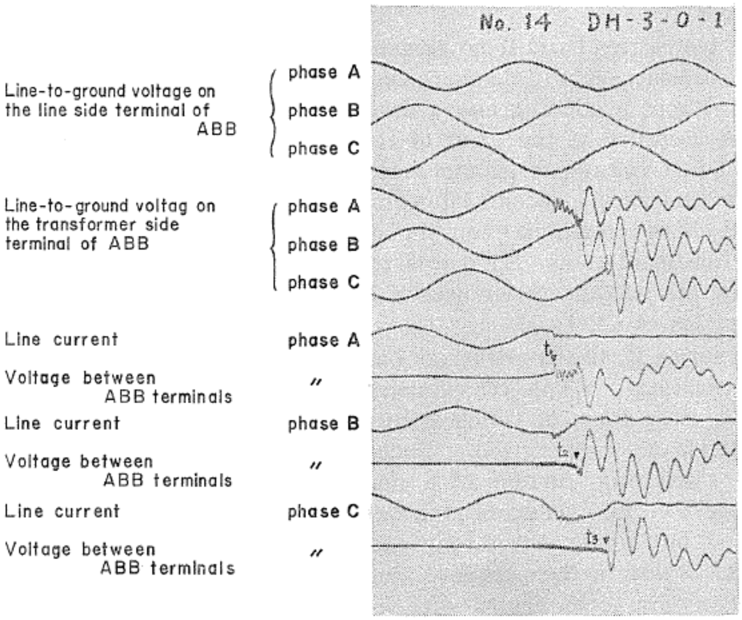

FIG. 3. Cathode-ray oscillograms of test No. 14

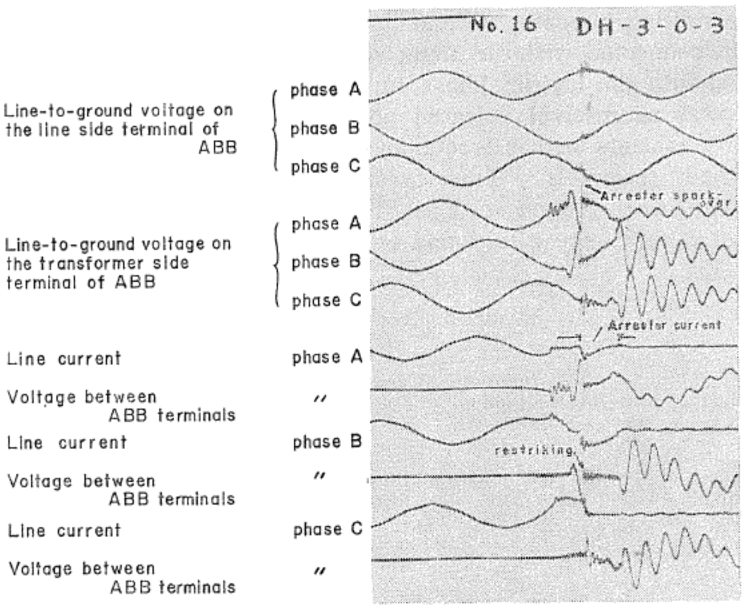

FIG. 4. Cathode-ray oscillagrams of test No. 16

arrester sparkover was taken place at the crest of an abruptly rising transient of the line-to-ground voltage on phase A induced by a single restriking on phase B. The arrester current is shown in Fig. 5 (a) together with the voltage transients observed on the secondary and tertiary windings at the same time. The

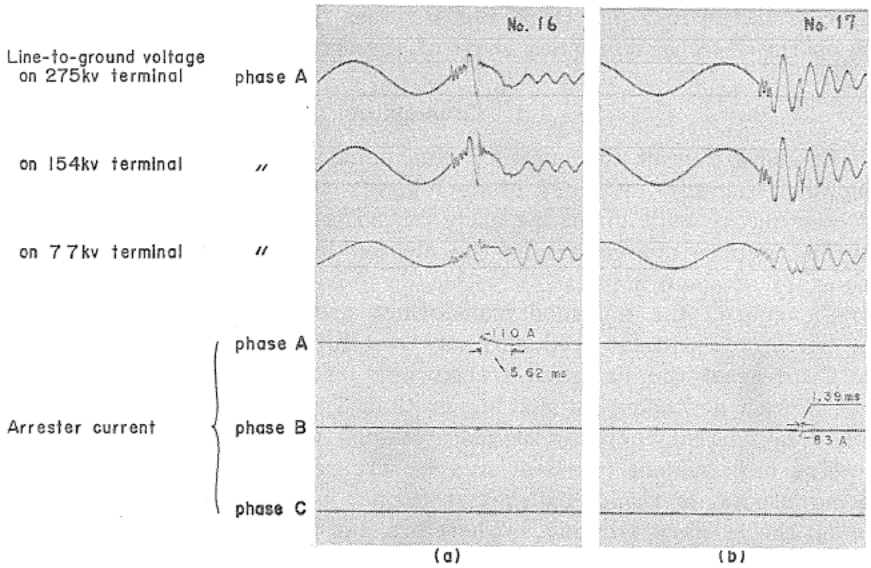

FIG. 5. Cathode-ray oscillograms of switching surges recorded on 220 mva transformer terminals and arrester currents

second sparkover occurred to phase B in test No. 17, just after the last clearing of the current on phase C. This performance was caused by the trivial crest peaking due to the unfavourable superposition of an additional transient with higher frequency of 2 kc/s, on the intial crest of violent transient with lower frequency of 430 c/s in the last period of switching operation as shown quite likely at t_3 in Fig. 3. By that time, the transformer bank had been already de-energized together with its protective arresters, no external energy being able to be supplied. Accordingly, the discharging period of the arrester was reached only

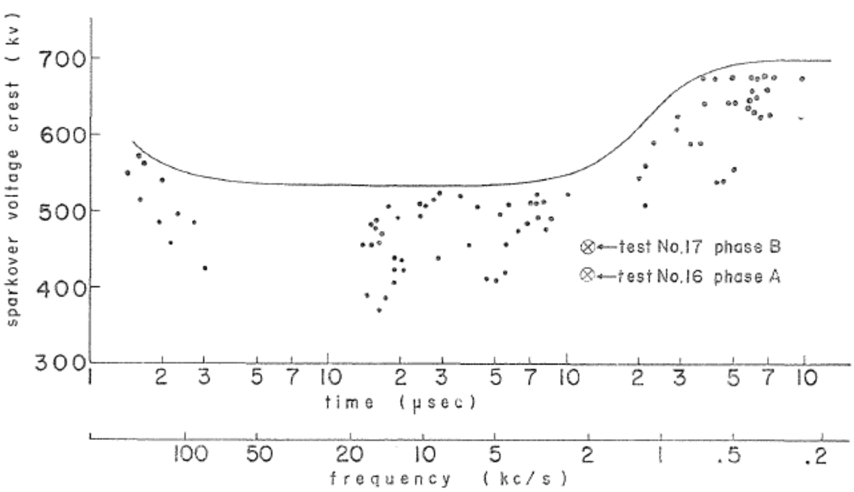

FIG. 6. 260 kv arrester V-t characteristics associated with the results obtained in this field test

1.39 msec as shown in Fig. 5 (b). Fig. 6 shows the above mentioned sparkover voltage on the *V-t* characteristics chart of the arrester used.

4. Conclusion

(1) De-energizing of the unloaded line could be performed without any re-striking and, therefore, without producing any switching surge, while slightly higher overvoltage built up in the early period just after energized.

(2) The trapped charge left on the cleared line leaked off slowly with the time constant of about 3 sec.

(3) Clearing of the unloaded transformer under the normally excited state may be performed without producing any switching surge.

(4) Clearing of the unloaded transformer just after energized might be accompanied with switching surges higher than 2 times the normal line-to-ground voltage. The current chopping played a leading role for the event.

(5) The most violent transient surges were recorded even in the normal interrupting process of the unloaded transformer bank connected with the shunt reactor on the tertiary winding. Therefore, the switching operation under this condition can not be recommended.

(6) Such a de-energizing operation brought about the arrester sparkover in two cases. The crest of transient voltages, reached 415 kv and 470 kv with the frequency of 2 kc/s, and, in spite of falling in the region of rather lower value of the expected sparkover voltage, led to the arrester sparkover.