Discussion

W. G. Hartle (General Electric Company, Philadelphia, Pa.): From the illustrations I notice that conventional outdoor circuit breakers and disconnecting switches rated 34.5 kv were mounted inside a building unit underground. Also, the authors mention that a considerable amount of earth was moved out, a building constructed, and then the building covered with earth so that it is not visible.

Inasmuch as completely metal-enclosed cubicles, including a power circuit breaker, isolation disconnecting switches, and current transformers, are built by several electric equipment manufacturers, I wonder if the use of this equipment was considered at the time this substation was designed. These metal-enclosed cubicles are built with either air blast or oil breakers and include segregation of the phases (faults can be only phase to ground), and safety interlocking between the isolation disconnecting switches and the power breaker. With air breakers the inherent hazards of oil fires are eliminated and maintenance is reduced to the point where it is practically negligible.

These units also provide the smallest cubicle content for the functions involved. Therefore, it would appear that less earth would have had to be moved, and a smaller building could have been built to house these functions had metal-enclosed equipment been used.

C. M. Short and **F. C. Osborn:** In the initial design stages of the underground distributing station, manufacturers of 34.5-kv metal-clad indoor switchgear were requested to submit preliminary designs and cost estimates for switchgear to perform the functions as shown on the single-line wiring diagram. The designs submitted showed that the use of metal-clad indoor switchgear would reduce the necessary excavation by 720 cubic yards and save 2,000 square feet of floor space. One disadvantage of the metal-clad switchgear was its height, which would have required that the ceiling be 7 feet 6 inches higher and would have resulted in a 2-level station.

The decisive factor, however, was cost. The manufacturers' estimated price for the metal-clad switchgear was 70% higher than the actual installed cost of the outdoor type of equipment, even after adding the extra excavation and building costs. Part of this difference in cost can be attributed to favorable land costs and ease of excavation, and part to the low prices for 34.5-kv outdoor circuit breakers in effect at the time this equipment was purchased. An evaluation of cost for a similar station using present-day prices might well result in a different station design.

In the past 3 or 4 years this Department has made increasing use of 34.5 kv to serve large office and commercial buildings. The advantages in using metal-clad gear for these installations are quite obvious and it is hoped that the increasing demand for this type of equipment will enable the manfacturers to develop more compact switchgear requiring less space, especially with reference to height, and at a competitive price.

Lightning Arrester Field Test Equipment and Results

H. LINCK
ASSOCIATE MEMBER AIEE

Synopsis: Lightning arresters play an important role in the protection of power system insulation against damage by surge voltages. Many arresters which have been in service a considerable number of years are still expected to provide this protection even for insulation that may not possess the strength as specified for new apparatus. The results of various methods used in the past to check arrester condition in the field are often questionable. A novel field test method for lightning arresters has therefore been developed. Impulse sparkover and power frequency leakage tests in the field can be carried out, with portable test equipment, on line-type and station-type lightning arresters with single-unit ratings up to 37 kv. Design and operating principles of this equipment are described; the field test results indicate that with the new method it is possible reliably to detect arresters not performing according to requirements.

On POWER SYSTEMS equipped with lightning arresters, apparatus insulation strength is co-ordinated with the protective level provided by the arrester. It is common practice to check and maintain apparatus insulation during its service life, but means to determine reliably, in the field, the effectiveness of lightning arresters have seldom been applied in the past. Laboratory tests do reveal arrester performance, but they require bulky and sensitive equipment not practical for field use. Arrester field checks carried out by means of potential gradient or low-voltage leakage tests give no direct indication of the protective qualities of an arrester, and the value of these tests is frequently uncertain.

The development of portable field test equipment for the testing of line- and station-type lightning arresters was undertaken 3 years ago.[1] This development was based on the following conclusions drawn from experience gained by extensive laboratory tests of arresters removed from service:

1. If lightning arrester damage occurs due to excessive surge or power follow current, the arrester spark gaps will usually be damaged because valve block puncture or overheating increases the duration and magnitude of the power follow current.
2. Condensation, moisture ingress, or partial breakdown of the arrester internal insulation frequently leads to the corrosion or contamination of spark electrode surfaces.
3. A power frequency leakage test carried out with a voltage close to but somewhat below the arrester rating is suitable for detecting arresters having severe internal damage.

Based on these observations, it was postulated that an impulse sparkover field test combined with a power frequency leakage test would lead to the detection of the majority of defective arresters.

Equipment for Impulse Sparkover Field Tests

The Impulse Generator

Impulse voltages up to several hundred kv are required for a sparkover test of lightning arresters installed on subtransmission and transmission systems. The

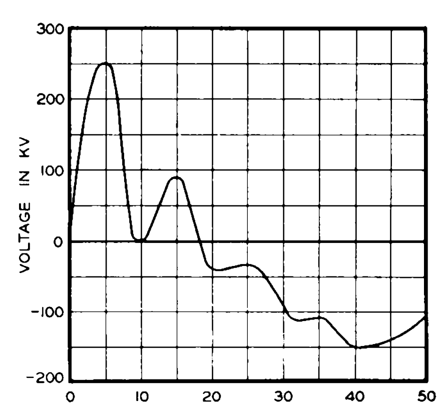

Fig. 1. Waveform produced by impulse generator

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H. Linck is with the Hydro-Electric Power Commission of Ontario, Toronto, Ont., Canada.

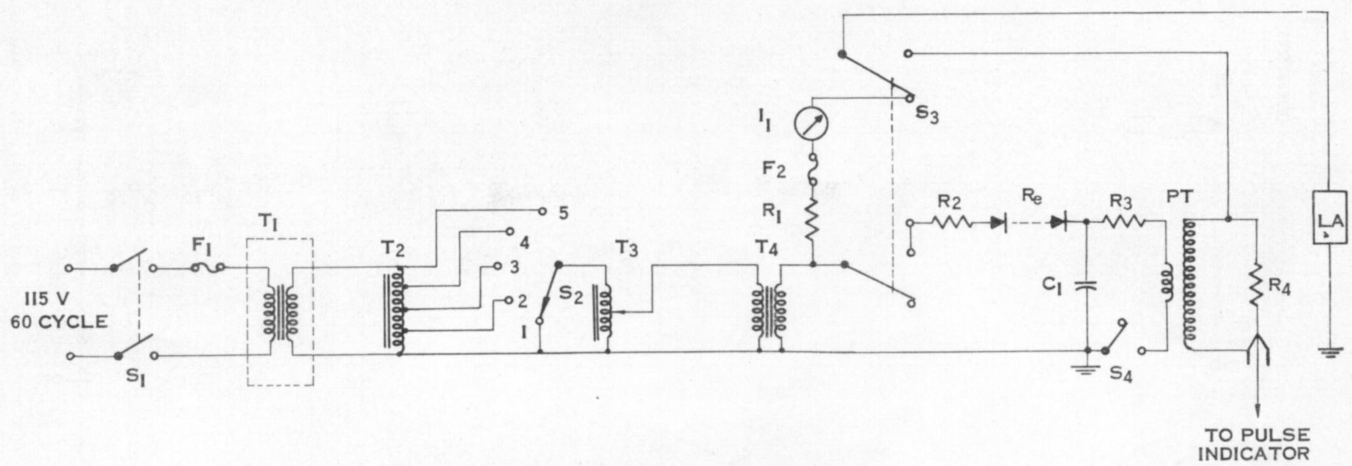

Fig. 2. Basic circuit diagram of impulse generator including power supply

conventional impulse generator, using a bank of high-voltage capacitors, is inconvenient in the field because its weight is considerable and the necessary adjustments are sometimes critical. Experiments in the laboratory with the use of an air-core pulse transformer (Appendix I) showed that the test voltage of nonstandard waveshape, Fig. 1, produced by this transformer, is well suited for sparkover measurements of arresters, giving test values similar to those obtained with the standard $1^1/_2$x40-μsec (microsecond) wave. With the relatively slow voltage rise to crest of approximately 5 μsec, problems of test lead length and measuring accuracy are minimized.

The pulse transformer has a voltage ratio of 12 to 1; only 21 kv are required on its primary side to produce the maximum rated test voltage of 250 kv. A basic diagram of the pulse generating circuit is shown in Fig. 2 (for component values see Appendix I); it functions as follows:

Capacitor C_1 is charged from a d-c source rated at 25 kv, 5 ma (milliamperes) The charging voltage is adjusted with Variac T_3 to a value corresponding to the desired test voltage. When the charge of C_1 is completed, the solenoid-operated high-voltage switch S_4 is closed and C_1 discharges through R_3 and the pulse transformer primary. Transformer winding inductance and capacitance act as a resonating circuit and produce the described voltage wave. Load resistance R_4, situated concentrically inside the cylindrical high-voltage winding, acts as a potential divider. A coaxial cable provides the connection to the pulse-indicating circuit. Through stepping switch S_2, three test voltage ranges, 0–80 kv, 0–140 kv, and 0–250 kv, are available, with the low range covering arrester ratings up to 20 kv, the medium range for 25- and 30-kv arresters, and the high range for arresters having sparkover voltages above 140 kv. Fig. 3 shows the test set.

The Impulse Indicator

Originally, a peak-reading voltmeter was used to indicate the arrester sparkover voltage directly.[1] Considerations concerning the most effective way of arrester testing in the field lead to the conclusion that it is not necessary to determine accurately the actual sparkover level as long as this level falls between tolerable lower and higher limits.

The principle employed with the impulse indicator now in use is as follows: A voltage indicator consisting of a thyratron tube with a continuously variable attenuator in the grid circuit operates when the grid signal reaches the trigger level of the tube. This trigger level can be adjusted with the calibrated potentiometer serving as the attenuator. If the signal applied to the attenuator input terminals produces a grid signal at least equal to the tube trigger voltage, then the thyratron will operate and switch on a signal light through a relay in the tube cathode circuit. If the input signal is below the trigger level, the signal light will not come on. By setting the attenuator control to a certain value, it is therefore possible to determine whether or not an input signal reaches the preset indicator value. In conjunction with the potential divider incorporated in the high-voltage pulse transformer, the indicator dial can be calibrated in kilovolts of pulse transformer output.

A current indicator working on the same principle operates a second signal light, indicating increased current flow in the arrester ground lead during sparkover.

With the two indicators one can determine whether or not the arrester sparked over, and whether sparkover took place below or above a preset voltage level. Circuit diagrams and component values for the indicator are shown in Fig. 4 and Appendix I respectively. For further details on the impulse indicator see Appendix II.

Power Frequency Leakage Test

The impulse sparkover test can conveniently be supplemented by a power frequency leakage test, with the use of the rectifier transformer of the d-c supply. This transformer is rated at 35 kv, 5 ma, and it can be used for leakage measurements on arresters rated up to 37 kv. A milliammeter for leakage measurements, mounted on the power supply box, is directly connected in the high-voltage lead to the arrester. A high-voltage switch is mounted on the pulse transformer, facilitating an immediate change of the test circuit from leakage to impulse test.

Test Procedures and Calibrations

Leakage Test

Before testing for sparkover, the leakage test is performed. After connecting the test leads, the high-voltage switch is moved into its leakage test position. Then the output voltage of the rectifier transformer is gradually raised with Variac T_3 to a value equal to 90% of the

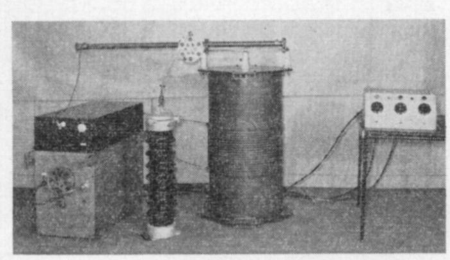

Fig. 3. Lightning arrester field test set

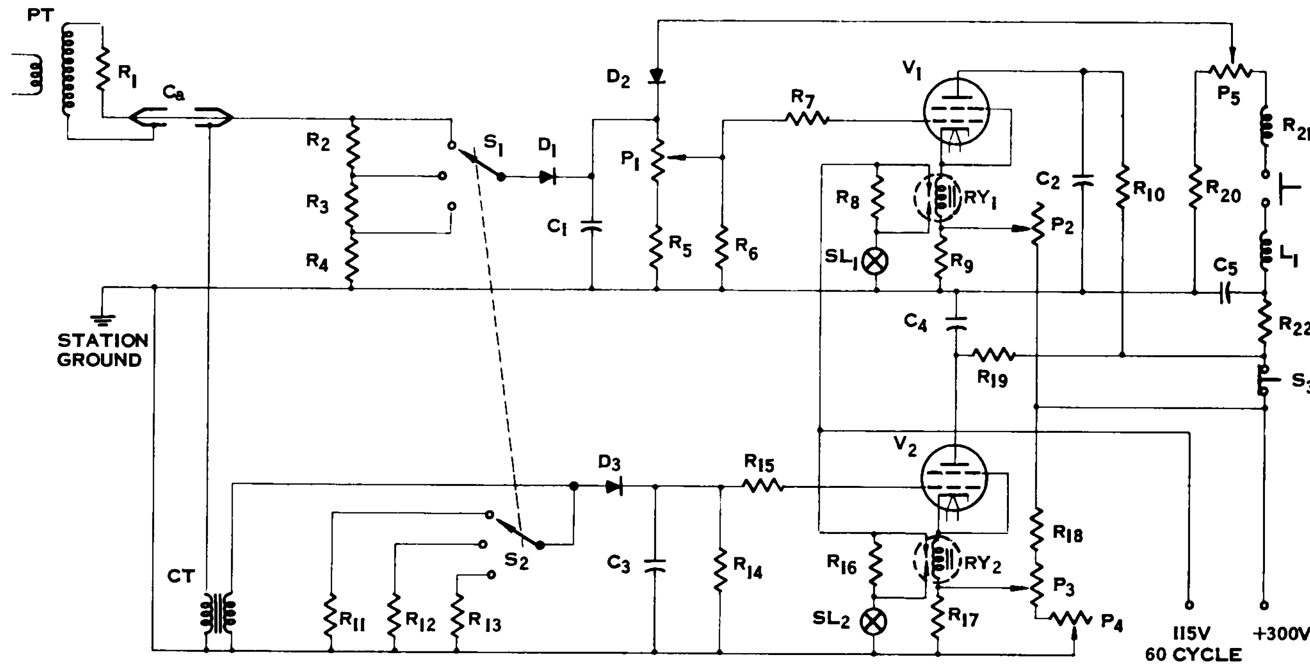

Fig. 4. Basic circuit diagram of pulse indicator

arrester rating. If the milliammeter reading is more than 2 ma above the test equipment internal leakage, the arrester is rejected.

The current flowing through the capacitance of the test lead to ground affects the milliammeter reading. In Fig. 5, test set leakage is shown as a function of lead length.

Impulse Sparkover Test

For each arrester type and rating to be tested, minimum and maximum permissible sparkover values were laid down (Table I). Arresters sparking over, near or above the higher limit, provide insufficient protective margin and must be replaced. Sparkover considerably below the lower limit usually indicates some internal arrester damage, and such units should also be removed from service.

For the impulse test the high-voltage switch is moved into its proper position, and the voltage indicator dial is set at the minimum sparkover limit for the arrester under test, for instance 60 kv for a 30-kv line-type arrester. Then, a test impulse slightly higher than the indicator setting, say, 70 kv, is applied. If the voltage indicator light only comes on, one knows that the arrester did not operate. If both voltage and current indicator lights appear, the arrester must have sparked over between 60 and 70 kv. Operation of the current indicator only would indicate arrester sparkover below 60 kv. If the arrester did not operate, the indicator dial is then adjusted to the maximum sparkover limit, or 150 kv for the 30-kv arrester. With a test voltage of 170 kv, the indicator lights will show arrester sparkover in the same manner as for the previous test. A more accurate value for the sparkover voltage can be determined by choosing intermediate voltage levels. As some arresters perform quite erratically, six voltage applications are made at each level. Erratic sparkover is considered serious only if the sparkover voltages approach the tolerable limits.

Voltage calibrations of the pulse transformer output taking into account the effect of test lead length were performed for each test voltage range. Fig. 6 shows that lead lengths up to 100 feet have only a minor effect on voltage magnitude. The calibration of the voltage indicator dial was carried out by determining the relationship between test voltage and minimum trigger voltage for various dial positions; see Fig. 7. The error produced by variations of the thyratron operating characteristics is $\pm 2.5\%$.

A calibrating circuit incorporated in the pulse indicator provides a convenient means for checking the indicator calibration in the field. A set of 12.5-centi-

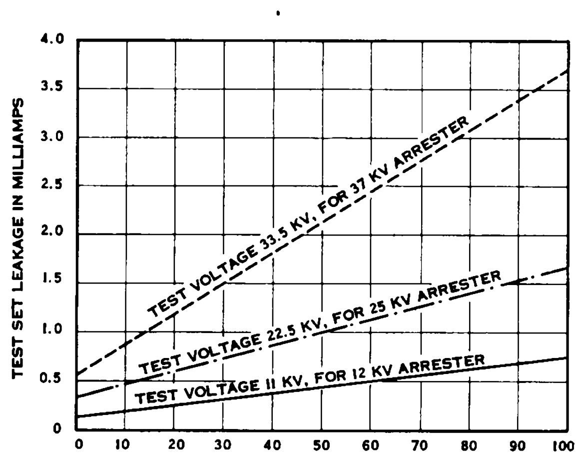

Fig. 5 (left). Effect of lead length on test set leakage current

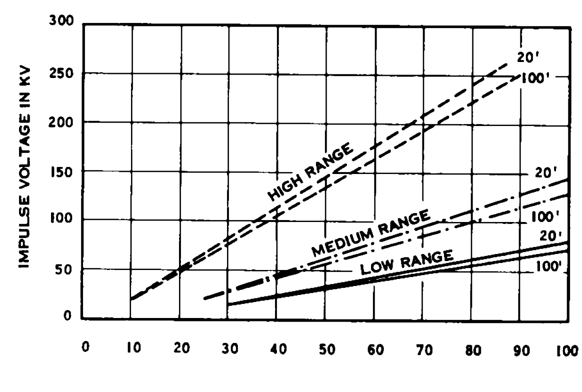

Fig. 6 (right). Impulse test voltage: effect of lead length

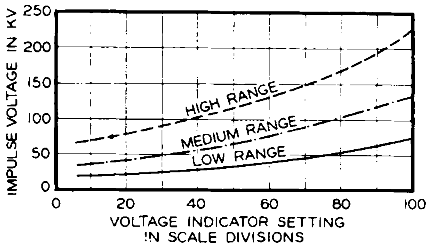

Fig. 7. Voltage indicator calibration

meter spheres is used in the field for calibrations of the pulse transformer output voltage.

Field Experience and Results

To date, 1,527 lightning arresters at 187 transformer and generating stations were tested during a 10-month period. A large percentage of these arresters are equipped with live-line clamps and were conveniently accessible for testing. Other arresters were tested during service interruptions for regular maintenance work. The test equipment, installed on a 25-square-foot trailer, was moved as close as possible to the arrester location. In some cases, the equipment had to be carried to the station. When station power was not available, a 1,000-volt-ampere motor generator set supplied 115 volts at 60 cycles. Field experience has resulted in useful suggestions for minor changes in station design in order to facilitate future arrester tests on a routine basis.

The test results were most frequently reviewed on the spot, and the local maintenance group was immediately informed if an arrester showed poor performance during the test. Older arrester types were found to have a larger percentage of defective units than newer types, and station types generally performed better than line types. In Table II, the number of units tested and rejected is shown for each age group. With the large amount of test data available, it was possible to evaluate statistically the relative sparkover performance of different arrester types; the results of this study are presented in Table III. The statistical method used is briefly explained in Appendix III.

Inspection of Arresters Removed from Service

One hundred and eight arresters condemned or questionable on the basis of field test results were shipped to the laboratory and opened for inspection. The following causes for arresters failing to pass the tests were established:

1. Ineffective weather seal, including cracked end castings, with moisture or water entering the arrester. This kind of defect was observed on certain line-type arresters, and it frequently resulted in severe spark gap corrosion or internal insulation breakdown.

2. Severe corrosion of surfaces between valve blocks and contact pressure plates of the older station-type arresters with ventilating holes in their bottom plates. High sparkover and discharge voltages resulted from this defect.

3. Inherently high sparkover of the older line-type arresters, without any pronounced defect showing. These units are not performing according to present-day standards.

4. Erratic sparkover of line-type arresters with rough gap electrode surfaces due to poor manufacturing control.

5. Arresters internally damaged by severe service duty, resulting in the puncture of valve and grading resistors, severe gap pitting and heavy carbonizing of internal parts.

Before inspection, many of these units were retested in the laboratory with both the field test and the standard impulse test equipment; the results generally agreed with the original field test, except for cases where a change in moisture or water content could have taken place, or where sparkover was very erratic.

Conclusions

1. Recognizing the need for improved lightning arrester field tests, a method using portable equipment was developed for impulse sparkover and power frequency leakage measurements on arresters in service.

2. Extensive field tests led to the detection of a significantly large number of lightning arresters not performing to test specifications.

Table I. Lightning Arrester Tolerable Impulse Sparkover Limits

Arrester Type	Rating, Kv	Sparkover Limits	
		Minimum*	Maximum†
Station	6	12	25
	12	25	50
	18	35	75
	24	50	100
	30	60	120
	37	75	145
Line	20	40	110
	25	50	110
	30	60	150
	37	75	185

* Minimum impulse sparkover for station and line type of arresters is specified as approximately equal to arrester rating $\times \sqrt{2} \times 1.45$.

† Maximum impulse sparkover is specified for station type arresters approximately 10% higher than values published in reference 3, and for line-type arresters as 75% of the associated equipment BIL.

Table II. Lightning Arrester Rejects

Arrester Type	Approximate Service, Years	Units Tested	Units With Sparkover		Leakage High	Total Rejects	
			High	Low		No.	Per Cent
Station	20	61	15	0	5	18*	29.5
	15	109	0	1	5	6	5.5
	10	136	0	3	0	3	2.2
	5	54	0	0	0	0	0
	2	61	0	0	0	0	0
Line	20	225	28	10	0	38	16.9
	10–15	518	26	42	19	75*	14.5
	5	161	0	4	1	5	3.1
	2	60	0	0	0	0	0

* Including units having unsatisfactory sparkover as well as high leakage.

Table III. Relative Sparkover Performance of Arrester Types

Type		Rating, Kv	Age, Years	No. of Samples	Sparkover Range, Kv	Mean Sparkover Value, Kv	Sample Variance, Kv^2	Sample Standard Deviation	
								Kv	Per Cent
Station	IA	11.5	20	30	27–70	41.53	104.74	10.23	24.7
	IB	12	15	69	22–46	30.43	25.16	5.02	16.5
	IC	12	10	47	22–37	28.76	7.76	2.79	9.7
	ID	12	2	12	29–42	33.1	18.22	4.27	12.9
Line	IE	25	20	109	45–155	88.3	479.73	21.9	24.8
	IF	25	12	136	25–135	63.75	539.91	23.24	36.5
	IIA	25	12	55	65–155	84.45	223.77	14.96	17.7
	IG	25	2	10	63–74	65.50	16.06	4.01	6.1
	IH	30	20	67	45–165	90.52	419.04	20.47	22.7
	IJ	30	12	165	15–175	81.3	563.69	23.74	29.2
	IIB	30	12	83	55–125	89.7	261.8	16.18	18.1
	IIIA	30	12	29	84–160	119.72	366.56	19.15	16.0
	IIC	30	5	47	55–105	81.6	105.55	10.27	12.6
	IIIB	30	5	12	54–115	74.42	256.08	16.00	21.5
	IK	30	2	34	64–87	75.76	21.7	4.66	6.15

3. For arresters removed from service after the field test and retested at the laboratory, the field test results were confirmed. Causes of arrester defects could be established from the visual inspection of arrester internal parts.

4. A statistical analysis confirmed field observations that certain arrester types give more reliable service than others.

Appendix I. Nomenclature and Component Values

Circuit Components for the Impulse Generator: Fig. 2

S_1 = main switch, 115 volts, 60 cycles
S_2 = coarse voltage control switch
position 1, off
position 2, impulse low
position 3, impulse medium
position 4, impulse high
position 5, leakage
S_3 = high-voltage switch, impulse leakage
S_4 = capacitor discharge switch
F_1 = ten-ampere fuse
F_2 = 25-ma fuse
T_1 = constant-voltage transformer, 115 volts, 250 va (volt-amperes)
T_2 = step transformer, 115/10–30–50–115 volts
T_3 = Variac, zero to 120 volts
T_4 = rectifier transformer, 115/35,000 volts, 5 ma
PT = high-voltage pulse transformer
R_1 = 250 kilohms, 10 watts
R_2 = 250 kilohms, 10 watts
R_3 = 2.5 ohms, noninductive
R_4 = 51 kilohms, 250-kv noninductive
I_1 = milliammeter, zero to ten ma
R_6 = selenium rectifier, 14×2.5 kv, 10 ma
C_1 = 0.5 μf (microfarad), 25 kv
LA = test specimen

Circuit Components for Pulse Indicator: Fig. 4

S_1, S_2 = sensitivity range switches
S_3 = re-set switch
S_4 = calibration switch
C_a = coaxial cable
L_1 = inductance, 70 turns of no. 18 wire on $1^1/_2''$ diameter form
PT = high-voltage pulse transformer
CT = current pulse transformer, 2/20 turns on steel core
V_1, V_2 = thyratron *2D21*
SL_1 = voltage-indicating light
SL_2 = current-indicating light
P_1 = 0–250 kilohms, 2 watts
P_2 = 0–250 kilohms, 2 watts
P_3 = 0–1 kilohms, 10 watts
P_4 = 0–500 ohms, 5 watts
P_5 = 0–100 ohms, 2 watts
D_1 = diode *M500*
D_2 = diode *M500*
D_3 = diode *M500*
C_1 = 0.005 μf, 500 volts
$C_2 = C_4$ = 0.5 μf, 500 volts
C_3 = 0.001 μf, 500 volts
C_5 = 0.1 μf, 500 volts
R_{Y1}, R_{Y2} = mercury relay
R_1 = 3×17 kilohms, 250 kv, noninductive
R_2 = 25 ohms, 1 watt
R_3 = 10 ohms, 1 watt
R_4 = 11 ohms, 1 watt
R_5 = 78 kilohms, 1 watt
R_6 = 300 kilohms, 1 watt
R_7 = 47 kilohms, 1 watt
R_8 = 5 kilohms, 10 watts
R_9 = 4.7 kilohms, 2 watts
R_{10} = 12 kilohms, 5 watts
R_{11} = 60 ohms, 1 watt
R_{12} = 25 ohms, 1 watt
R_{13} = 9 ohms, 1 watt
R_{14} = 1 megohm, 1 watt
R_{15} = 10 kilohms, 1 watt
R_{16} = 5 kilohms, 10 watts
R_{17} = 10 kilohms, 2 watts
R_{18} = 8.2 kilohms, 10 watts
R_{19} = 12 kilohms, 5 watts
R_{20} = 50 ohms, 5 watts
R_{21} = 700 ohms, 10 watts
R_{22} = 1 megohm, 2 watts

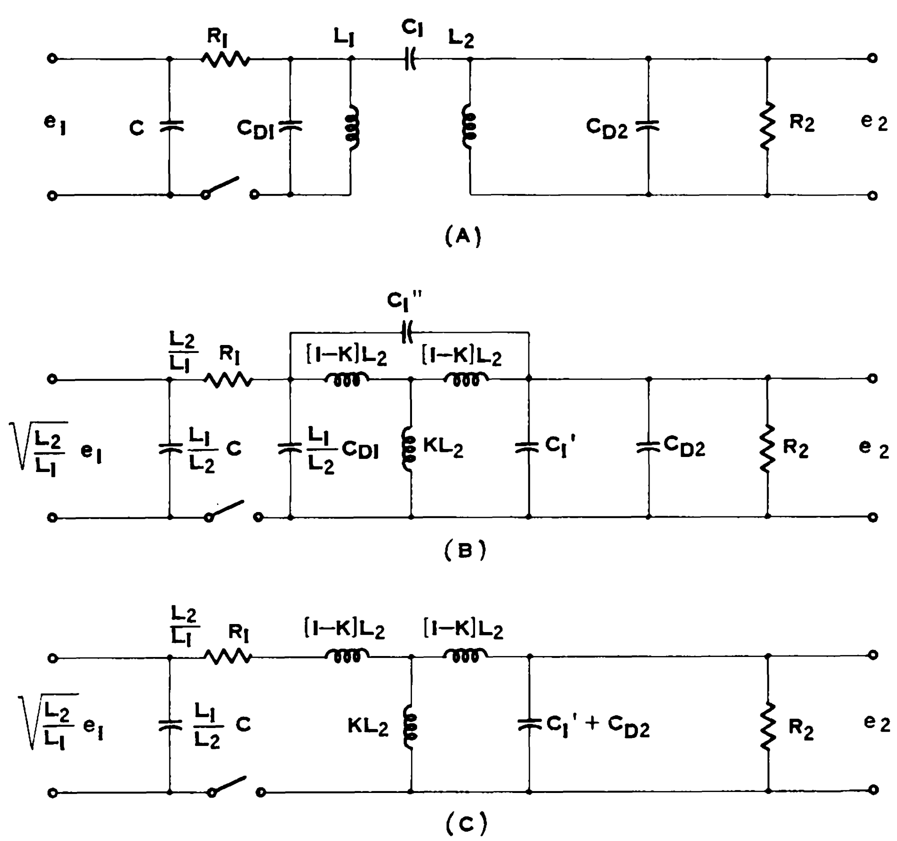

Fig. 8. Circuit diagrams of high-voltage pulse generating network

A—Actual circuit
B—Complete equivalent circuit
C—Simplified equivalent circuit

Air-Core Pulse Transformer Design

NETWORK PRODUCING HIGH-VOLTAGE IMPULSES FOR ARRESTER SPARKOVER TEST

Theoretical calculations and measurements on analog circuits were carried out to determine the required circuit constants. Fig. 8(A) shows the actual circuit diagram of the network with the following components:

C = primary discharge capacitor
S = high-voltage switch to initiate the discharge of C
R_1 = primary damping resistor
L_1 = low-voltage winding of pulse transformer
C_{D1} = distributed capacitance of low-voltage winding
C_1 = coupling capacitance between low-voltage and high-voltage windings
L_2 = high-voltage winding of pulse transformer
C_{D2} = distributed capacitance of high-voltage winding
R_2 = load resistance and potential divider
e_1 = discharge voltage of capacitor C
e_2 = pulse transformer high-voltage output

For calculations and analog studies, the circuit in Fig. 8(A) was replaced by the equivalent circuit shown in (B). With all components transferred to the transformer secondary side the following obtains:

K = coefficient of coupling
KL_2 = mutual inductance
$(1-K)L_2$ = leakage inductance
$C_1'' = C_1$ = coupling capacitance
$C_1 = (L_1/L_2-1)^2C_1$
= energy storage capacitance due to capacitive coupling between primary and secondary windings

The constants L_1/L_2C_{D1}, and C_1'', for the range of values under consideration, have a negligible effect on the voltage waveshape, and the simplified circuit of Fig. 8(C) was used to determine the final design values for the pulse transformer.

From Fig. 1 it can be seen that the voltage wave consists of two components:

1. A damped oscillation reaching its first crest in 5 μsec. The frequency of 100 kc is mainly determined by the components $C_1'+C_{D2}$, $(1-K)L_2$, KL_2, and R_2. The circuit impedance as seen by the arrester before it sparks over is 48 kilohms.

Table IV. Pulse Transformer Design Values

	Primary Winding	Secondary Winding
Inductance	180 μhenrys	72 millihenrys
Distributed capacitance	20 picofarads	20 picofarads
Number of turns	19	684
Winding diameter	20 inches	15 inches
Winding length	11.3 inches	30 inches
Wire size	no. 6, bare	no. 22, enamelled

Coupling factor between primary and secondary windings: $K=0.5$.
Capacitance between primary and secondary windings: $C_1=20$ picofarads.

2. A damped oscillation with a frequency of 16.5 kc and a maximum peak of 56% of that of the 100 kc oscillation. The lower frequency is mainly determined by the circuit constants L_1/L_2C, $(1-K)L_2$ and KL_2; the impedance is 13 kilohms.

Lightning arrester sparkover occurs on the initial 5-μsec peak when the circuit impedance is 48 kilohms. At the instant of sparkover, the test circuit impedance drops down sharply due the capacitive coupling between primary and secondary, producing a short transient current peak of approximately 50 amperes. When sparkover is established the 100-kc oscillation disappears and the circuit impedance of 13 kilohms allows a discharge current flow of 5 to 10 amperes.

Pulse Transformer Construction

The final design values for the pulse transformer are shown in Table IV.

Assuming an average flashover distance of 8 kv per inch, tubular Hercolite coil forms with a length of 38 inches for the primary winding, and 36 inches for the secondary winding were selected.

Both windings are of the cylindrical, single-layer type, with the secondary winding mounted concentrically inside the primary winding. The vertically arranged coil forms are fastened to Bakelite plates serving as base and top of the transformer. This arrangement provides adequate electrical and mechanical strength for field use. The weight of the complete transformer including load resistor is 110 pounds.

Appendix II. The Pulse Indicator

The Voltage Indicator: Fig. 4

The output voltage of the high-voltage pulse transformer is attenuated by the potential divider consisting of high-voltage resistor R_1 and the low-voltage resistors R_2, R_3 and R_4 through coaxial cable C_a. Range switch S_1, mechanically coupled to the coarse control switch of the high-voltage supply, provides the proper indicator sensitivity range for each test voltage range. The attenuated test signal is stabilized by the pulse-stretching circuit formed by diode D_1 and capacitor C_1. Potentiometer P_1 provides the trigger level control for thyratron V_1. The minimum trigger level of V_1 depends on its cathode bias voltage and is set with potentiometer P_2 to a value of 15 volts. When V_1 is triggered by a test signal, the cathode current flows through the coil of relay R_{Y1} and cathode resistor R_9 to ground. The contacts of R_{Y1} close, supplying 115 volts to the voltage signal light SL_1. After each operation, the voltage indicator light must be switched off by momentarily interrupting the thyratron cathode current with reset switch S_3.

An internal calibrating circuit, consisting of capacitor C_5, inductance L_1, switch S_4, resistors R_{21}, R_{20}, and potentiometer P_6, provides a calibrating signal, similar in shape to that of the attenuated test voltage, which is fed into the trigger control potentiometer P_1 through diode D_2. Changes in indicator sensitivity, for instance, those due to tube deterioration, can be detected with this calibrating signal without a high-voltage calibration.

The Discharge Current Indicator

The function of the current indicator is to indicate the presence of discharge current when the arrester operates. Arresters installed in service usually are directly grounded to the station structure; therefore a current monitoring device must be connected in the return lead between the station ground and the low end of the pulse transformer high-voltage winding. For testing purposes, a ground lead connects the chassis of the pulse indicator with the station ground near the arrester location. In Fig. 4 is shown how a current return path is provided from the station ground through the primary winding of a small pulse transformer CT and back to the high-voltage pulse transformer through the sheath of coaxial cable C_a. The inner conductor of this cable connects the lower end of high-voltage resistor R_1 to the input terminal of the voltage indicator.

When the arrester operates during the impulse sparkover test, the discharge current induces a voltage in the secondary winding of pulse transformer CT (Fig. 4), whose magnitude depends on the values of the load resistors R_{11}, R_{12}, and R_{13}. Three current sensitivity ranges are provided by switch S_2 which is mechanically coupled to the test voltage and voltage indicator range switches. Fine control of the current indicator trigger level is achieved by coupling bias-control potentiometer P_3 to the shaft of Variac T_2; see Fig. 2. A pulse-stretching circuit consisting of D_3 and C_3 applies the signal to thyratron V_2. Operation of V_2 and current indicator light SL_2 are identical to that of the voltage indicator. After each operation the current indicator light has to be reset with switch S_3.

Appendix III. Statistical Evaluation of Arrester Sparkover Performance

To describe the sparkover test data for each arrester group, and to determine the scatter of test values, the following terms are used:

Arithmetic mean sparkover value

$$=\frac{\text{sum of all sparkover values of group}}{\text{number of samples tested}}$$

The standard deviation from the mean sparkover value is

$$S=\sqrt{\frac{\Sigma(X_i-\bar{X})^2}{n-1}}\text{ kv}$$

where

X_i = individual test value, kv
$\bar{X}$ = arithmetic mean of all sparkover values of group, kv
n = number of samples per group

or

$$S(\%)=\frac{S(\text{kv})}{\bar{X}(\text{kv})}\times 100$$

The sample variance $S^2=(\Sigma(X_i-\bar{X})^2)/(n-1)$ (kv^2).

As the number of arresters per group varies from 10 to 165, a Bartlett m-test was applied to determine the homogeneity of the sample variances.[2] It was found that the influence of the sample sizes is negligible, and that the values for the standard deviations are comparable.

References

1. Lightning Arrester Field Tests, H. Linck. *AIEE CP58-160* (available on request).
2. Biometrika Tables for Statisticians, Vol. I, E. S. Pearson, H. O. Hartley. Cambridge University Press, Cambridge, England, 1954.
3. A Lightning Arrester Application Guide for Substations and Stations, Committee Report. *AIEE CP51-285* (not available).

Discussion

William H. Eason (General Electric Company, Pittsfield, Mass.): This paper should attract wide interest because of the natural desire of operating people for a dependable field test of intermediate-class (line type) and station-class lightning arresters. Leakage current tests at or near rated voltage are generally agreed to be the best practical field test possible, and it is also generally accepted that such a test will not detect damaged valve disks or damaged gaps unless the latter have actually become short-circuited.

A few users make 60-cycle sparkover tests, but this is not recommended because of the danger of damaging the gap-shunting resistors by 60-cycle overvoltage, particularly if they are of the nonlinear, voltage-sensitive type. Here, then is a clear advantage of the author's proposal: the impulse sparkover test eliminates the danger of overheating of the gap-shunting resistors, provided, of course, that the test is not repeated unreasonably within a short period. The equipment required is somewhat more complex than that for a power frequency sparkover test but the author has tried to minimize this as far as the operator is concerned by a go-no-go signal light indicator.