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SHORT-CIRCUIT PROTECTION FOR DIRECT-CURRENT SUBSTATIONS

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The author includes an outline of the progress made in protection of direct-current machinery from short circuits since the publication of a paper at Atlantic City on this subject.

The improvements mentioned include the refinement and perfection in details of the flash barriers; a new design of high-speed circuit breaker for both direct-current substations and electric locomotives; a new high reluctanc ecommutating pole for 60-cycle synchronous converters and a new design of protected brush holder. An instructive analysis of conditions during direct-current short circuits is shown by several photographs, oscillographs and diagrams. Special reference is made to operating results on the electric zone of the Chicago, Milwaukee and St. Paul Railroad.

THE investigation of means to prevent flashing of direct-current machinery and development of suitable equipment has been continued since the presentation of the paper on "Protection from Flashing for Direct-Current Apparatus," by Mr. J. L. Burnham and the writer at the Atlantic City Convention in 1918.* This paper outlined in a general way the results obtained with quite a number of different methods of reducing or preventing flashing under extreme overload or short-circuit conditions.

This study indicated that a special form of flash barrier with arc coolers and a new form of high-speed breaker with current-limiting resistance had proved the most promising development. Tests showed that the two types of protection provided complete protection from a "dead" short circuit caused by short-circuiting the terminals of a machine without external resistance.

*Trans. XXXVII Part II, 1919, pages 1341-1365.

These two types of protection have been further perfected and are now in regular commercial use. They are used either separately or together and in many instances considered standard railway practise.

The improved type of high-speed breaker described has been perfected in all details as shown in Figs. 1 and 2.

Thirteen of these breakers were installed by the Chicago, Milwaukee & St. Paul Railroad as part of the electrification of their Coast and Cascade Divisions. Fig. 2 shows the breaker with the arc chute installed but with covers removed. This view shows the calibrating rheostat used to set tripping point of the breaker. Description of this breaker will not be repeated as general theory of operation and design is described in the paper referred to, and more detailed description of the perfected breaker will be described in article by Mr. J. F. Tritle in the April number of the *General Electric Review.*

This breaker was used instead of the first type of circuit breaker which has given successful operation during the past three years in the fourteen substations of the 440-mile original electrification of the Chicago, Milwaukee & St. Paul Railroad. This new breaker has the advantage of lower cost and greater simplicity.

One of these breakers is used with each of the 2000-kw., 3000-volt, synchronous motor-generator sets in the Tacoma, Renton, Cedar Falls, Hyak and Cle Elum substations and the remaining five breakers on each of the new gearless type passenger locomotives. On account of the lower cost of these breakers and advantages of using the "unit" system throughout, each of the sets is protected by its own high-speed breaker instead of one breaker per substation, the arrangement in the original installation.

The general connections, location of circuit breaker, etc., are shown in Fig. 3.

The circuit breakers for the substations and locomotives are exactly alike with exception of interlocking and calibration for tripping points.

The circuit breakers were given a very exhaustive test in connection with one of the 2000-kw. sets in test before shipment, with very successful operation in all details. It was found that the generators could be short-circuited with only sufficient cable in the circuit to connect the different meter shunts, short-circuiting contactor and high-speed breaker without damaging machines in any way and with practically

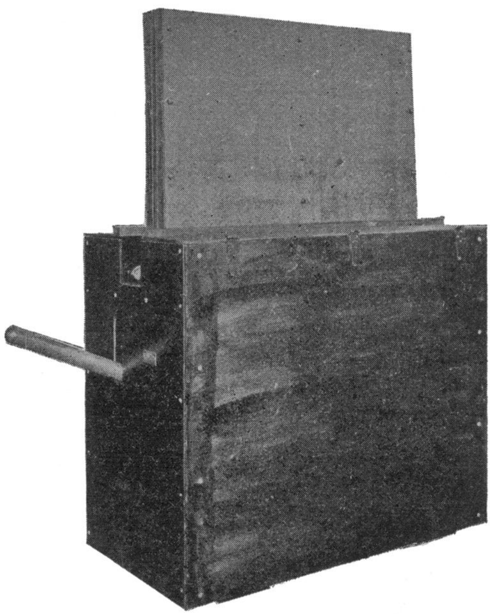

FIG. 1—1500-AMPERE, 3000-VOLT, D-C. HIGH-SPEED CIRCUIT BREAKER

no flashing at the brushes. Figs. 4 and 5 show photographs of two of these short circuits, one of which gave so slight a flash that it can hardly be seen while the other shows very slight flashing in the flash barriers. Fig. 6 shows oscillogram of one of these short circuits giving a very good idea of the high speed of the breaker and the protection afforded. It will be noted that the current was limited to about 7000 amperes and reduced to three times load in 0.016 seconds. The current starts to decrease in 0.0081 of a second and it will be noted that the area representing the load which would be likely to cause flash-over is very small and of such short duration that very little gas or arc could be formed. Fig. 7 has been prepared to show graphically the much greater

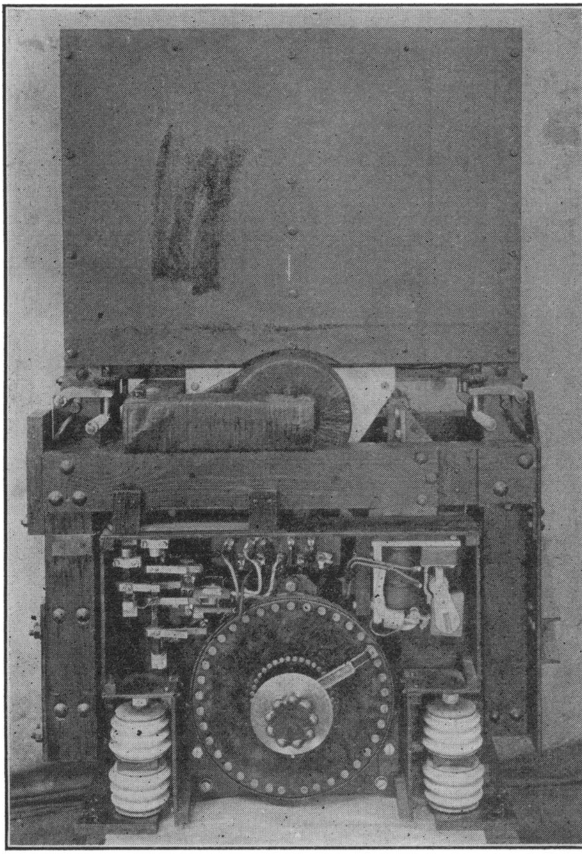

FIG. 2—1500-AMPERE, 3000-VOLT D-C. HIGH-SPEED CIRCUIT BREAKER WITH ASBESTOS LUMBER CASING REMOVED SHOWING RHEOSTAT USED TO OBTAIN DIFFERENT TRIPPING POINTS

protection afforded by circuit breaker of such high speed over that obtained with the usual type of breaker. This figure shows the current curve of a 2000-kw., 3000-volt machine on short circuit when protected by the high-speed breaker and by a standard 3000-volt breaker designed for higher speed than usually obtained with regular carbon-break 600-volt breakers. The area of each curve above the load which would cause flashing has been cross-hatched to show the ratio between the two areas which gives a very good idea of the value of the great speed and the reason there is so little flashing. During these tests about one photograph out of four was similar

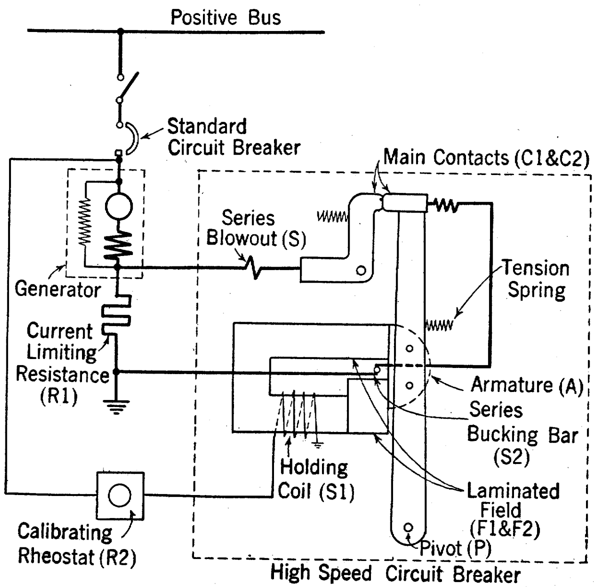

Fig. 3—General Connections of High-Speed Circuit Breaker

to Fig. 4, while the others were of the character shown in Fig. 5.

A special reliability or endurance test was made as part of the acceptance tests of the breaker during which about 65 short circuits of different magnitude, fifteen of which were "dead" short circuits, were applied at intervals of about 2½ minutes without cleaning the commutators or giving them any attention whatever. At the conclusion of these tests, five "dead" short circuits were thrown on the set within ten minutes. At the end of these tests, commutators were in excellent condition without any need of cleaning or attention of any kind.

These circuit breakers are now in regular operation and reports received of their operation have been very gratifying.

The application of the high-speed circuit breaker to direct-current electric locomotives is another distinct advance as in addition to protecting the appar-

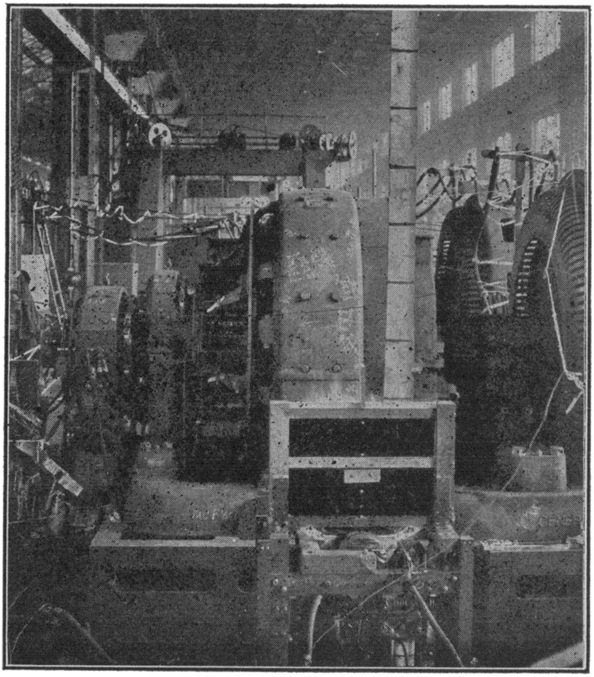

FIG. 4—SHORT CIRCUIT ON 2000-KW., 3000-VOLT MOTOR-GENERATOR SET PROTECTED BY HIGH-SPEED CIRCUIT BREAKER AND FLASH BARRIERS. TRIPPING POINT 2550 AMPERES. LINE RESISTANCE 0. CURRENT LIMITING RESISTANCE 1.2 OHMS

atus on the locomotive, it prevents the short circuits from affecting the substations.

If both the substations and locomotives are equipped with this type of high-speed circuit breaker, current under maximum conditions would never reach a value much greater than 7000 amperes. The value of the maximum short-circuit current decreases very rapidly with distance from substation as shown in Fig. 8. These records were taken with a 1500-kw., 3000-volt

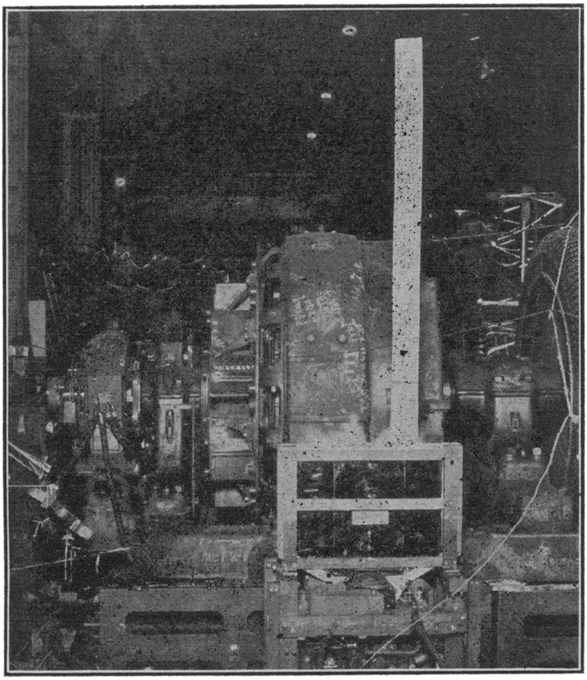

FIG. 5—SHORT CIRCUIT ON 2000-KW., 3000-VOLT MOTOR-GENERATOR SET PROTECTED BY HIGH-SPEED CIRCUIT BREAKER AND FLASH BARRIERS. TRIPPING POINT 2940 AMPERES. LINE RESISTANCE 0. CURRENT LIMITING RESISTANCE 1.2 OHMS

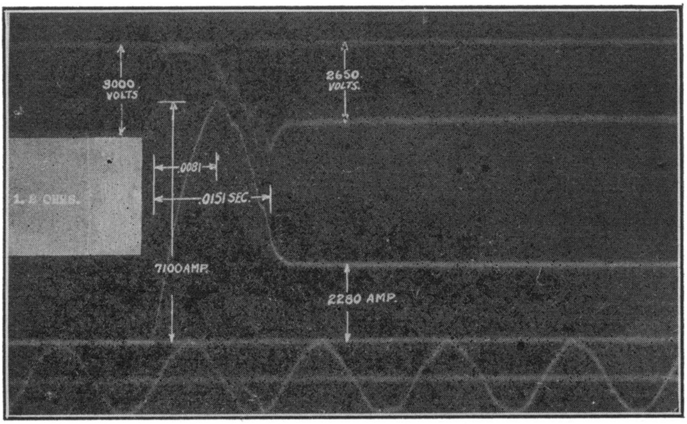

FIG. 6—SHORT CIRCUIT ON 2000-KW., 3000-VOLT MOTOR-GENERATOR SET PROTECTED BY HIGH-SPEED CIRCUIT BREAKER AND FLASH BARRIERS. TRIPPING POINT 2250 AMPERES

motor generator set connecting the overhead trolley consisting of two No. 4/0 wires directly to the 100-lb. track rails and closing the circuit at the substation. It will be noted that the maximum peak current is only 3600 amperes with short circuit 4800 ft. from the substation and 2860 amperes, 9600 ft. from the substation as compared with 7000 amperes "dead" short circuit across the terminals of the machine.

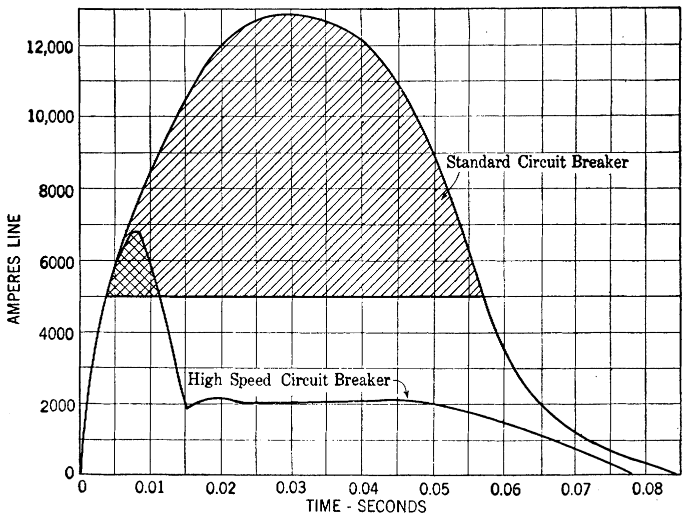

FIG. 7—SHORT CIRCUIT ON 2000-KW., 3000-VOLT MOTOR GENERATOR SET PROTECTED BY HIGH-SPEED CIRCUIT BREAKER WITH CURVE SHOWING CURRENT WHICH WOULD BE OBTAINED WITH STANDARD CIRCUIT BREAKER. RATIO OF THE AREA OF THE TWO CURVES ABOVE 5000 AMPERES GIVES INDICATION OF THE PROTECTION AFFORDED

The value of this type of protection was proved very conclusively during these tests due to the accidental grounding of one of the switchboard busbar insulators. The high-speed breaker inserted the current limiting resistance so quickly that some time was required to locate the trouble as burning at the grounded point was so slight as to be hardly noticeable, indicating that even under such extreme conditions current is reduced so quickly that sufficient time is not allowed to cause current to generate sufficient heat to cause destruction of the current-carrying parts.

Another of the incidental advantages of this type of protection is the elimination of disturbances on the a-c. side of synchronous converters or motor-generator sets ordinarily caused by d-c. short circuits due to the fact that the load is decreased so quickly that momentum of the armatures supplies the energy and the load is not increased materially on the a-c. side. The overload relays are therefore not affected, increasing very greatly the general operating efficiency of a substation, eliminating time required to start up set from the a-c. side, etc. After the occurrence of a short circuit it is only necessary for the operator to close the high-speed breaker and then the main switchboard breaker which is interlocked with the high-speed breaker after which the main switch is thrown in following regular switching practise. If the short circuit still persists, the high-speed breaker will again open but with no flashing or damage to brushes or

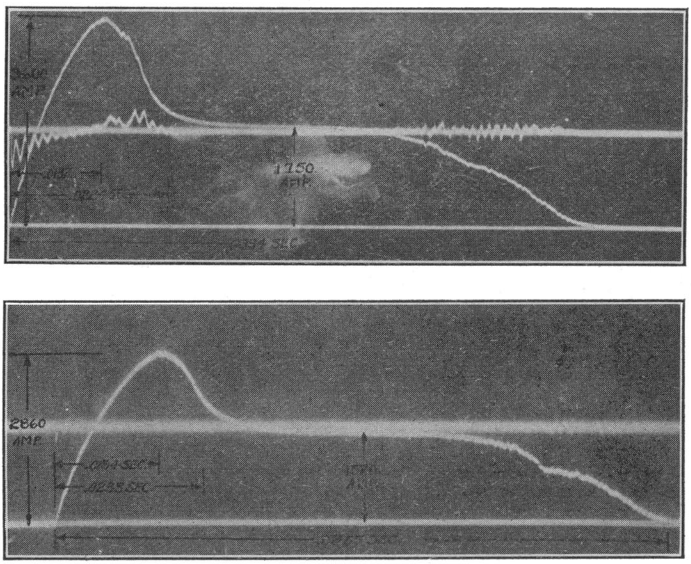

Fig. 8—Short Circuit on 1500-Kw. 3000-Volt Motor-Generator Set at Different Distances from Substation. Generators Protected by High-Speed Circuit Breaker and Flash Barriers

commutator and greatly decreased duty on the regular breaker.

The flash barriers described in the original paper have not been changed in any essential details, improvements being along the line of simpler construction, ease of removal for inspection and improvement in appearance.

These barriers with iron wire arc coolers are standard equipment on all 3000-volt motor-generator sets as well as on all machines used in connection with automatic substation control. Fig. 9 shows one of the 2000-kw., 3000-volt sets for the Milwaukee electrification equipped with these barriers, while Fig. 10

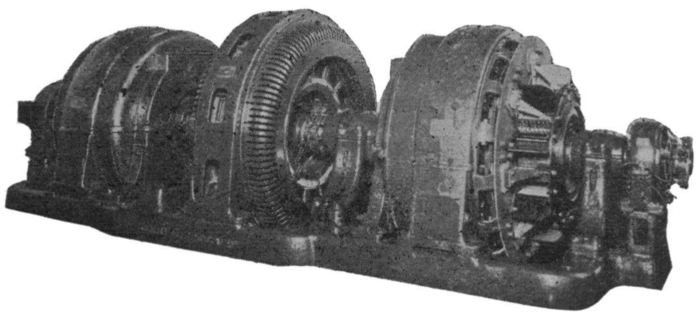

FIG. 9—2000-KW., 3000-VOLT D-C. SYNCHRONOUS MOTOR-GENERATOR SET EQUIPPED WITH FLASH BARRIERS

shows barriers for 600-1200-volt, 60-cycle, 500-kw. synchronous converter.

Flash barriers and high-speed circuit breaker are standard equipment on 1500 to 3000-volt substations and it is believed this practise will be extended to include 600 and 1200-volt apparatus.

Another advance in short-circuit protection is the protected type of brush holder recently perfected as shown in Fig. 11. This brush rigging is protected on all sides where flashing might occur by asbestos lumber so that an arc cannot readily hold between brush holders of opposite polarity and prevents the formation of iron or copper vapor which might cause a flash to the frame and cause damage to the brush rigging or commutator. A removable cover is provided for inspection and removal of brushes. It is made of an iron sheet for convenience as there has been no tendency for the arc to strike this part of the brush rigging during tests or in actual operation. It will be noted that this type of brush rigging lends itself very readily to the addition of flash barriers as shown in Fig. 10.

This type of brush rigging has been standardized for all 600-volt, 60-cycle synchronous converters.

The use of the high reluctance commutating pole is a very promising improvement which has just been made in 60-cycle, 600-volt synchronous converters

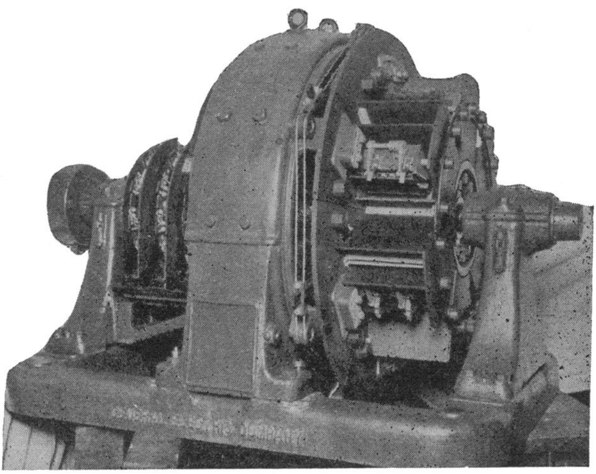

Fig. 10—500-Kw., 600/1200-Volt 60-Cycle Synchronous Converter Equipped with Flash Barriers

and has been standardized for all 60-cycle machines. Tests indicate that the use of these poles raises the flashing point at least 50 per cent. In actual commercial use the improvement is greater than indicated by this figure as a very great proportion of short circuits which originally caused flash-over would not cause flashing on machines equipped with this new type of commutating pole winding.

These improvements are of particular value for 60-cycle converters which are inherently more sensitive than 25-cycle converters.

Brief attention should be called to the great protection afforded by tapping the feeder at some dis-

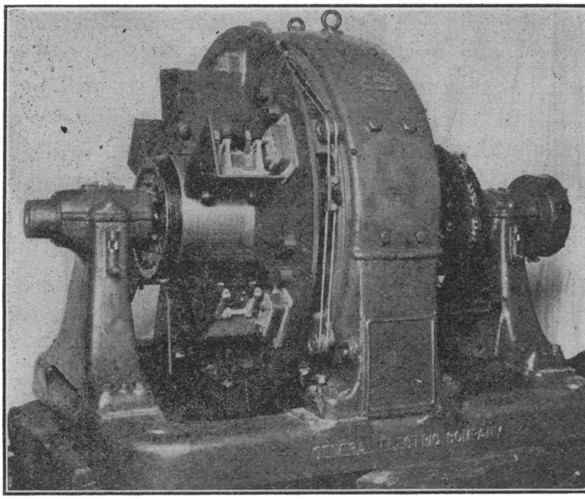

Fig. 11—500-Kw., 600/1200-Volt 60-Cycle Synchronous Converter with Protected Type of Brush Holder

tance from the substation. This is undoubtedly the cheapest type of protection which can be used but cannot be relied upon to prevent flashing over under extreme short circuits. A very slight amount of permanent resistance such as would be given by such an

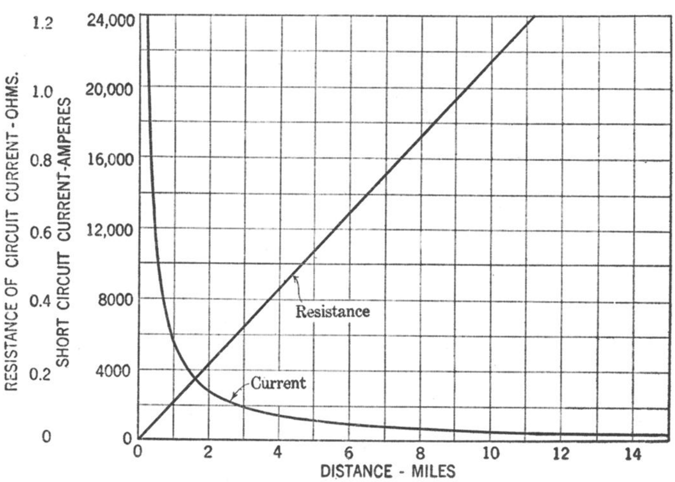

Fig. 12—Curve Showing Ratio of Short-Circuit Current to Distance From Substation

arrangement greatly reduces the number of flash-overs with very little loss of energy or voltage. Under ordinary conditions it is believed that the distance to the first tap need not be greater than 2000 ft. A greater distance than this causes an appreciable loss of energy and drop in voltage. Fig. 12 shows very clearly the great benefit of a small amount of resistance in reducing the maximum possible current on a short circuit.

If complete immunity is desired from short circuits, the high-speed circuit breaker and barriers undoubtedly offer the best known solution. With this protection, feeder taps can be connected to the overhead trolley directly at the substations, reducing losses to a minimum. Maintenance on the substation apparatus will also be decreased as burning from short circuits undoubtedly causes most of the wear and deterioration on brushes and commutator. Another particular advantage of this type of protection is that it can be applied to old generators or synchronous converters of any voltage without change in the machine itself.