

High-speed Circuit Breakers for Chicago, Milwaukee & St. Paul Electrification

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Each of the 14 substations in the 440-mile electric zone of the C., M. & St. P. Rwy. is now equipped with high-speed circuit breakers, some of which have been in operation for over a year. This protective device is connected into the negative return circuit between the ground and the negative bus, and it is in parallel with a limiting resistance which becomes effective immediately the breaker opens. The article below describes the details of construction of this unusual equipment to which brief reference was made in our July issue.—EDITOR.

To protect the generating apparatus in the Chicago, Milwaukee and St. Paul substations from flashovers that result from short circuits near the stations, high-speed circuit breakers of unusual characteristics have been developed and placed in operation. This protective apparatus operates with sufficient speed to check the rise of current caused by a short circuit before damage can be done to the generating apparatus, the necessary speed being of the order of a few thousandths of a second.

In the high-speed circuit breaker which has proved itself successful in operation, the rate of acceleration of the main and the secondary contacts is approximately 8,000 feet per second, and the contacts are released in a time as short as 0.003 second or less from the beginning of a short circuit. The time from the beginning of the rise in current caused by a short circuit until the secondary contacts part has been shown to be of the order of 0.004 second. This rate of speed can better be appreciated when it is considered that the ordinary switchboard circuit breaker requires about 0.10 to 0.15 second. The high-speed breaker will therefore in effect foresee the rise in current which is caused by short-circuit, and will insert in the line sufficient resistance to limit this rise to a safe value.

Many railroads have adopted the practice of running the feeders to some distance out from the station before tapping them into the trolley wire in order to insert an amount of feeder as resistance between the substation and the tapping-in point. It was obvious that if a device could be developed to protect the generators from flashovers due to short circuits, its use would permit of the feeders being tapped directly into the trolley at the substation. With this method of connection, the feeder resistance will be unnecessary and its losses will be eliminated.

The amount of the loss caused by the insertion of this protective feeder resistance is

quite considerable in many cases. On the Chicago, Milwaukee and St. Paul Railway preliminary calculations in connection with the electrification showed that quite an appreciable amount of power could be saved by the elimination of this additional feeder resistance. To accomplish this saving, work was started on the development of an air circuit breaker which would have such a high opening speed that the device could be used to insert resistance in the circuit quickly enough to prevent the short-circuit current from reaching a value that would cause the direct-current machinery to flash over. It was known that the circuit breaker would have to be designed to operate at a speed much higher than any previously attempted. Careful investigations demonstrated that the device must operate in a shorter time than is required for one commutator bar to pass from one brush stud to the next, i.e., less than one half cycle for that particular generator.

In each of the substations one of these high-speed breakers is connected into the negative return circuit between the ground and the negative bus. This location gives the maximum protection since the return circuit must pass through the limiting resistance in case of a flashover from positive to ground, for all the negative terminals, brush rigging, etc., are insulated for full generator voltage. Complete protection is assured by the high-speed circuit breaker being so interlocked with the regular switchboard air circuit breaker that the former must always be closed before the latter.

The fourteen 3000-volt, direct-current substations of the Chicago, Milwaukee & St. Paul Railway are equipped with this new type of circuit breaker and the first units installed have been in operation for nearly two years with very satisfactory results. Actual operation has demonstrated that, when protected by the high-speed circuit breaker, it is entirely practicable to operate direct-current substations with the feeders tapped into the

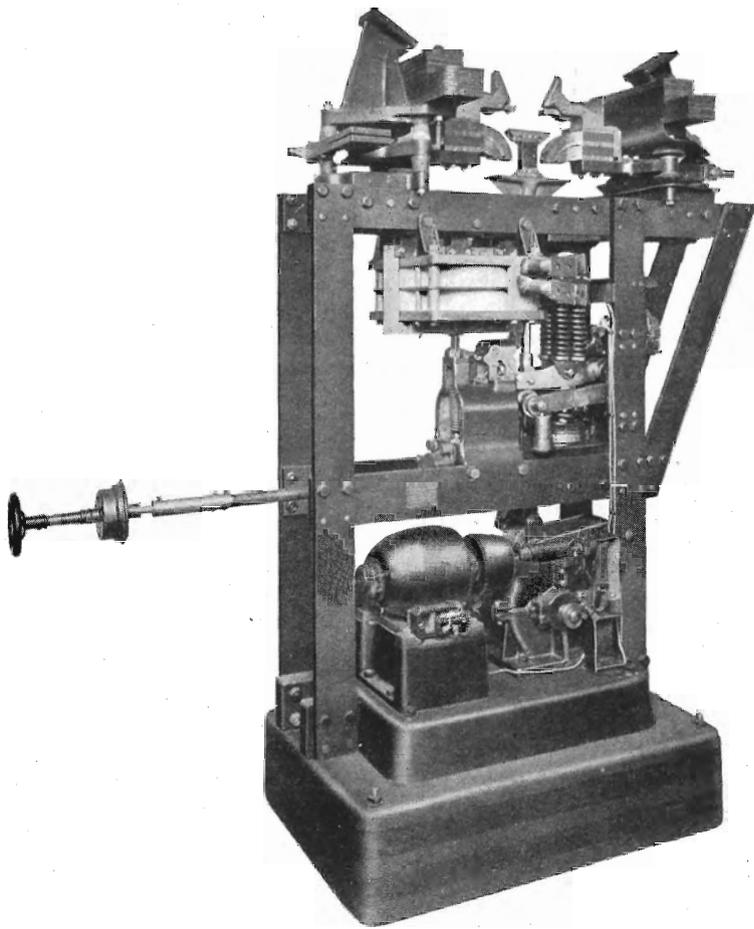


Fig. 1. View of High-speed Circuit Breakers with Arc Chute and Magnetic Blow-out Removed

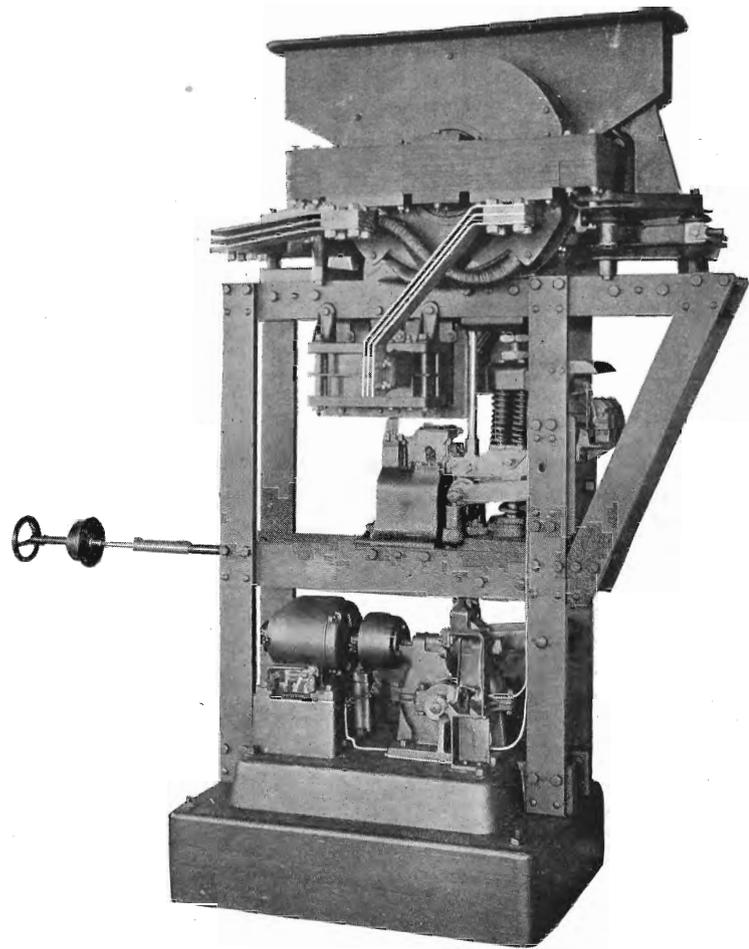


Fig. 2. Arc Chute and Magnetic Blow-out in Place

trolley system directly at the substation to eliminate the resistance losses occasioned by tapping in at some distance away, and that this is true even for a 3000-volt system which is the highest direct-current voltage used in railway work.

The high-speed circuit breakers installed are of the single-pole magnetic blowout type and are rated at 3600 volts, 3000 amperes direct-current. The circuit breaker and its mechanism are a self-contained unit mounted on a structural iron framework with a cast-iron base which, in turn, is mounted upon an insulated base to insulate the circuit breaker from the station floor. The circuit breaker can be closed either by hand at the breaker or by a motor controlled from the station switchboard. When closed by hand, a ratchet

of blowout, and therefore the blowout coils and trip coils of the breaker are connected in series in order that the blowout coils be excited at all times. The main and secondary contacts are mounted on a lever actuated by a group of compression springs that exert a force of about 8,000 pounds when the breaker is closed. A pressure of this magnitude is necessary in order to produce the rapid acceleration which high-speed operation requires.

The tripping is accomplished through a train of latches and levers actuated by a solenoid which has a specially laminated magnet frame and core to obtain a quick magnetic response to the short-circuit exciting current. The object in using a train of several latches is to enable the main latch to

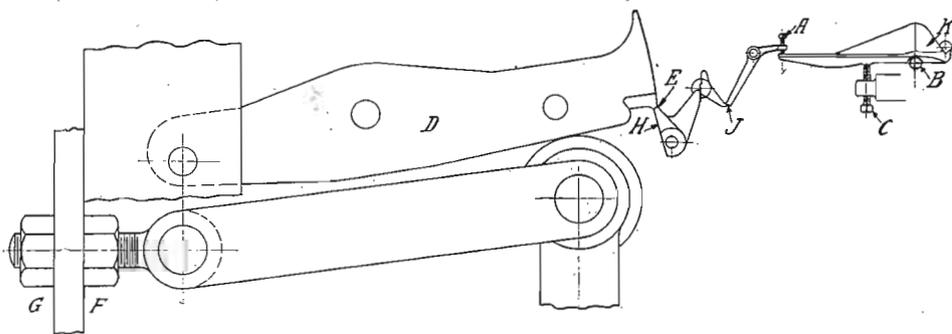


Fig. 3. Sketch showing Tripping Mechanism of High-speed Circuit Breaker

mechanism is employed. The closing of the breaker by means of the motor is accomplished by a cam mechanism operated through gears.

The main contact brushes are stationary and are of the familiar laminated brush structure. The movable contact is a solid copper forging which is made as light as possible in order to reduce the mass to be moved. The secondary contacts are located above the main contacts and a very ingenious design has been employed to insure their breaking after the main contacts have broken, to eliminate any possibility of the current-carrying parts of the main contacts being burned. All of the contacts are located in a blowout chute of insulating material designed to withstand the burning incident to the arc. The blowout magnet is of large cross section and is made up of laminated iron. The usual shunt arrangement of blowout coils it was found would not give a sufficient speed

be moved through a distance of $\frac{1}{8}$ inch by a solenoid which, in order to act in the time required, is able to move a distance of only about 0.001 inch and can exert a force of only about 200 pounds, while the main latch is subjected to a pressure of about 4000 pounds.

An adjustable tension spring, which directly opposes the pull of the solenoid, enables the circuit breaker to be calibrated in accordance with the varying number of generating units in the several stations.

The actual tripping takes place at the point *J* shown in Fig. 3. The solenoid applies its force at the point *B* that there may result a large and definite movement, which is later multiplied by the levers *A* and *K*. The latches *E* to *J* are specially formed to reduce the great pressure at *E* to such a value as can be handled by a small bearing surface at *J*.

When the breaker contacts open, the arc resistance becomes increasingly effective as

the breaker completes its operation, and after the lapse of about 0.008 second or less from the beginning of the short circuit, the resistance has increased to such a value that no further rise of current can take place.

The high-speed circuit breaker described in the foregoing has demonstrated in actual service that it will protect generating appara-

tus from all short circuits, and that it will not only prevent damage to the brush rigging, commutator, etc., but will relieve the duty on the switchboard air circuit breakers.

The remarkably high operating speed of the circuit breaker and the resulting protection against damage to the equipment is ably shown by the oscillographic record in Fig. 5.

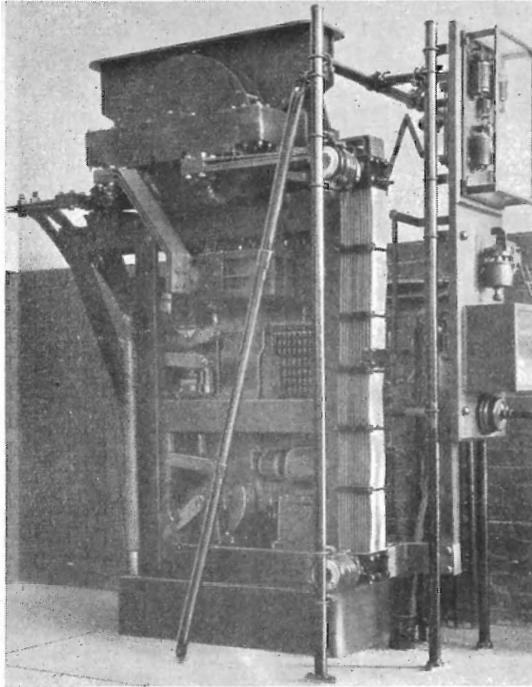


Fig. 4. High-speed Circuit Breaker
Installed in Substation

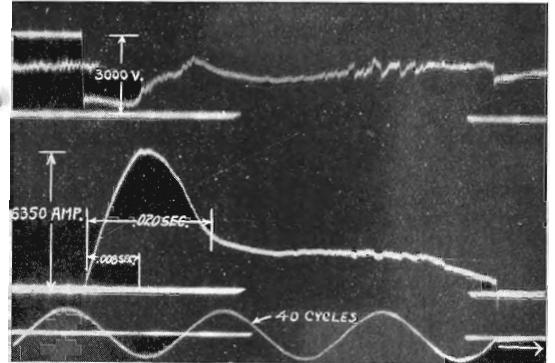


Fig. 5. Oscillogram showing Performance
of Circuit Breaker

The maximum current rise is less than ten times normal and this is quickly reduced by the circuit breaker to well within the commutating capacity of the generator. Another especially good feature of this method of protection is that none of the effects of the direct-current short circuits is transmitted through the motor-generator set to the alternating current side, thereby preventing any effects of the direct-current short-circuit disturbances from reaching the alternating-current supply system.