

NOTES ON OIL CIRCUIT BREAKERS FOR LARGE  
POWERS AND HIGH POTENTIALS

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### ABSTRACT OF PAPER

The paper gives a brief outline of some of the important developments in oil circuit breakers which have taken place within the last two or three years. Ideal conditions require that the current should not re-establish itself after passing the first zero value following the opening of the contacts, and this emphasizes the value of high opening speed in a circuit breaker. Breakers have been designed in which resistances were introduced to limit the current to a value readily ruptured, but as this principle is difficult of accomplishment, reactance has been successfully substituted for resistance. Reactance breakers have two sets of contacts, the main set which carries the normal current, and an auxiliary set which carries the reduced current after the reactance has been introduced by the opening of the main contacts. Breakers for any power and voltage, with all the usual methods of operation are now available.

## NOTES ON OIL CIRCUIT BREAKERS FOR LARGE POWERS AND HIGH POTENTIALS

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The purpose of this paper is to outline briefly the latest developments in oil circuit breakers for the largest powers and highest potentials.

The rapid increase in powers to be handled by switching apparatus in keeping step with the growth of generating and transforming apparatus has developed the need of oil breakers with breaking capacities much in excess of what has previously been obtainable. The former designs are now in many instances utterly inadequate.

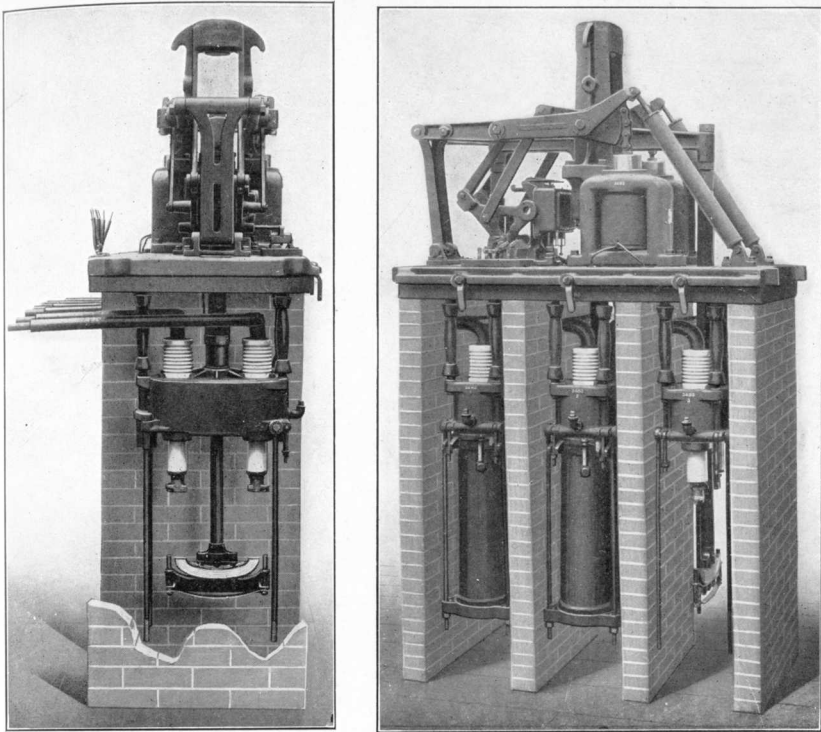
As an evidence of the common appreciation of the difficulty in obtaining competent circuit breakers, may be cited the tendency to employ current-limiting reactances on heavily powered systems.

Tests for obtaining data on which high-power breakers may be thoroughly tried out are only practicable on large power plants, which are rarely available for this purpose. It requires much courage and deep interest for an operator to hazard his machinery and service for obtaining data that, usually, will be used by the manufacturer rather than by the operator, although the latter may be the particular beneficiary. As a result, much circuit breaker development is based on field experience and observation rather than on logical consecutive tests usual with other apparatus. However, a number of important tests have been made within a few years, but these have only been at moderate voltages. So far as the writer is aware, no extensive high-potential tests have ever been conducted on oil circuit breakers.

The salient features of a modern breaker for a large plant (Fig. 1) are simplicity, accessibility, adequate rupturing capacity—which embodies strong tank construction, good head of oil over contacts, liberal expansion chamber over oil provided with vent, accelerated operation and good contacts with readily renewable arcing tips. The oscillogram (Fig. 2) well illustrates the operation of such a breaker. The speed of rupture ( $\frac{1}{2}$  cycle) is clearly shown by the smooth current curve until the last half-cycle when the voltage across the arc first appears and immediately becomes normal. This operation at 12,000 volts, 25 cycles, 12,000 amperes, was not manifested externally even by an appreciable show of smoke from the vents.

Considering the gradual increase in the rating of breakers it is noted that, as the current carrying capacity grows, the weight of the current-carrying parts becomes greater, and also the mechanism for operating these parts. In other words, the inertia of the breaker is increased and, also, the friction of the mechanism. Mechanical devices are available for accelerating any mass, as may be necessary, but this in turn demands means for bringing the accelerated mass quickly to rest at the end of the stroke. All of this becomes more difficult as the need for higher rates of opening, corresponding to increased voltages, and greater mass, corresponding to increased current-carrying capacities, are to be dealt with.

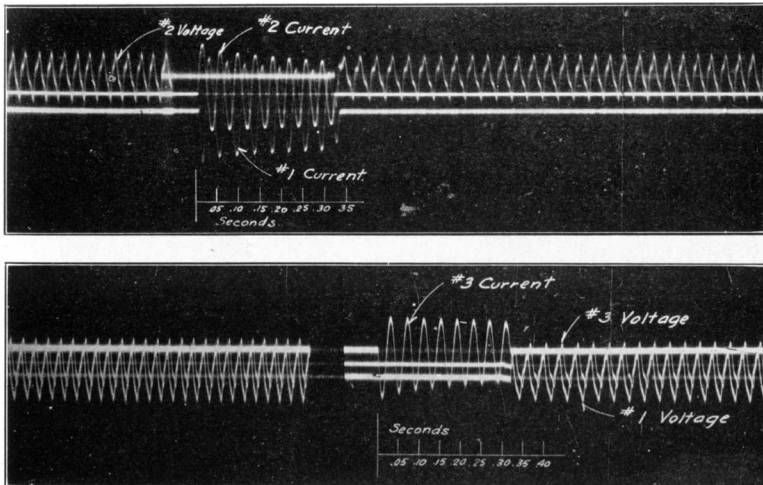
It is worth while to analyze briefly the characteristics of the ideal breaker, considered solely as a current-rupturing device, namely, neglecting its current-carrying function and other mechanical considerations. Ideally, the current of the circuit should not reestablish itself after passing the first zero value following the separation of the contacts. This means that in 60-cycle service not more than  $1/120$  (0.0083) of a second should elapse before the contacts have sufficiently separated to make the reestablishment of current impossible. With such a breaker the minimum energy will be dissipated between the contacts, and consequently with the least possibility of failure. In contrast to this, the more slowly operating breaker may allow the current to reestablish itself consecutively several times after the first separation of the contacts has occurred, and in this way may dissipate much energy, which is usually manifested in a mild way by smoke issuing from the oil tanks, and in a violent way by the bursting of the tanks, tearing them from their fastenings, or even quite complete destruction of the breaker.



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FIG. 1.—A MODERN CELL STRUCTURE OIL BREAKER.

For potentials up to 25,000 volts and systems of 40,000 to 120,000 kv-a., according to method of operation.

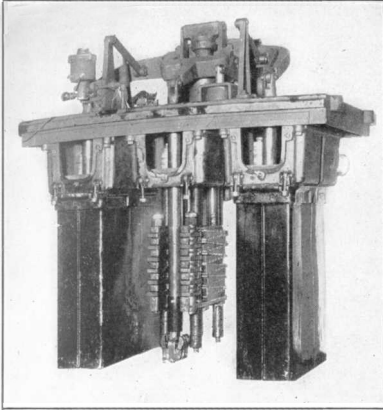


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FIG. 2.—OSCILLOGRAMS SHOWING RUPTURE OF HEAVY POWER CIRCUIT BY BREAKER ILLUSTRATED IN FIG. 1, 12,000 VOLTS, 12,000 AMPERES.

Note that current is ruptured in  $\frac{1}{2}$ -cycle after establishment of arc voltage, which itself endures but  $\frac{1}{2}$ -cycle and then becomes normal.

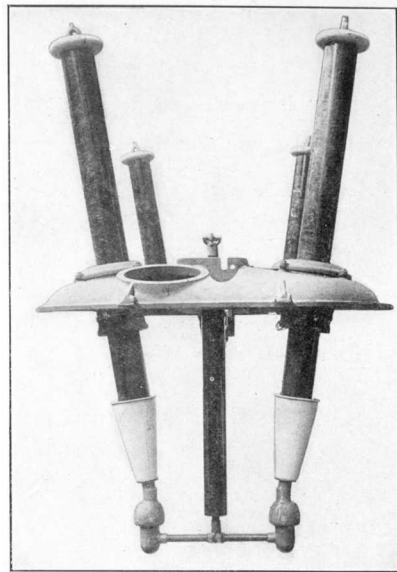




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FIG. 3.—AN EARLY SUCCESSFUL FORM OF THE RESISTANCE TYPE, PNEUMATICALLY OPERATED OIL CIRCUIT BREAKER.

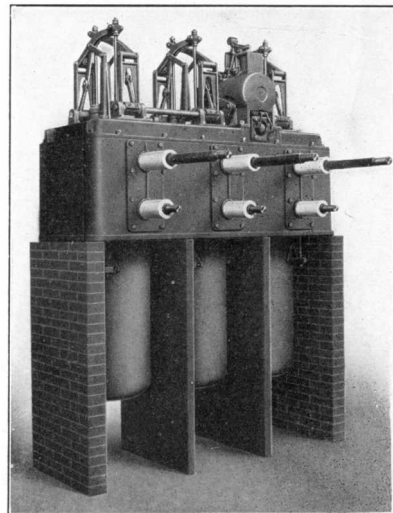
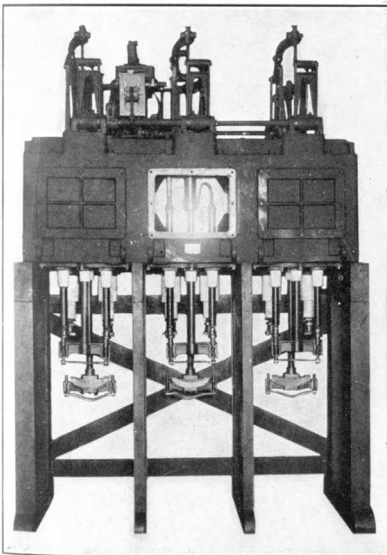
Note seven contacts which are passed over by contact fingers at end of operating rod, thus introducing the resistance by six steps into the circuit.



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FIG. 8.—INTERNAL VIEW OF SINGLE-POLE UNIT OF HIGH-ACCELERATION BREAKER

This design is especially adapted to high and extra high potentials. Tested to 420,000 volts.



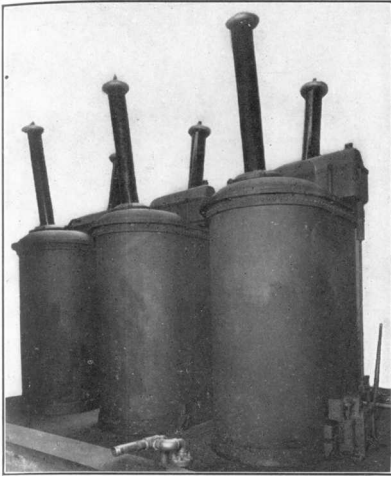
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FIGS. 6 AND 7.—REACTANCE BREAKER, RATING 1200 AMPERES, 15,000 VOLTS, FOR 200,000-H.P. PLANT.

Illustrates type built for service from 5000 to 25,000 volts. Reactance coils are exposed by removal of cover of middle pole.

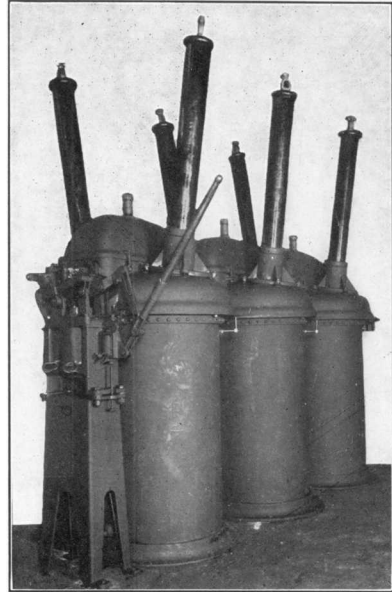






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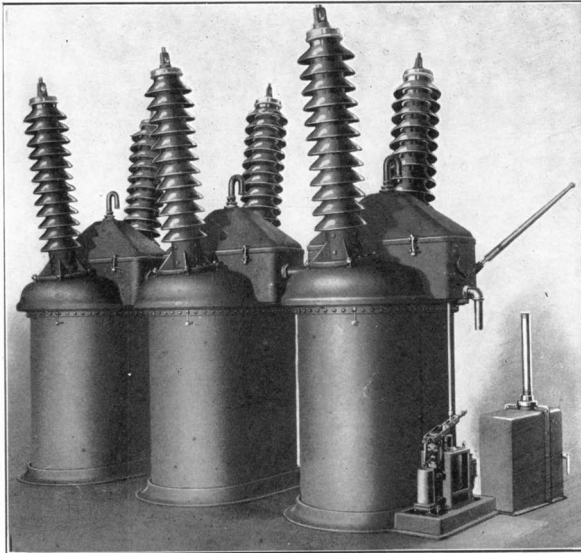
FIG. 9.—VIEW OF ASSEMBLED THREE POLES OF HIGH-ACCELERATION BREAKER. Interior of one pole shown in Fig. 8. Approximate dimensions: height, 16 ft.; floor space, 24 by 8 ft.



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FIG. 12.—A 110,000-VOLT, 600-AMPERE REACTANCE BREAKER.

Operating mechanism for either electrical or hand. Over-all floor space about 14 ft. by 5 ft. 8 in.; height, 12 ft. 6 in.



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FIG. 11—AN OUTDOOR, 110,000-VOLT, 300-AMPERE CIRCUIT BREAKER.

This illustrates a general type of design built in voltages from 40,000 to 165,000 volts.



The value of a high opening speed may be appreciated from the following analysis in which, for the sake of simplicity, assume temporarily that arcing between contacts does not influence the arc-quenching ability of the breaker. With a breaker adjustable as to speed of operation, arrange that after the contacts separate the rate of opening shall allow the current to hold for ten cycles. Readjust the breaker to hold for five cycles, for  $2\frac{1}{2}$  cycles, and for  $\frac{1}{2}$  cycle. Corresponding to each cycle, heat would be dissipated, and total amounts of heat proportionally of 10, 5,  $2\frac{1}{2}$  and  $\frac{1}{2}$  would, on an average, have been dissipated, for the current volume, voltage and length of arc were the same in each case. But the assumption that the arc gases would not affect the operation of the breaker is known to be incorrect. In fact, the presence of arc gases necessitates longer openings to rupture the currents. This, then, means that the slower the rate of opening, the greater must be the opening before rupture occurs, and this again increases the time of arcing, with corresponding dissipation of heat and probability of failure and damage. Any rate of opening faster than  $\frac{1}{2}$  cycle will gain nothing, as, on the average, the stored energy of the circuit may be assumed to appear as heat at the arc; hence if the arc holds only to the first zero ( $\frac{1}{2}$  cycle), the same stored energy of the circuit will have been dissipated. However, if the current is reestablished the circuit is recharged, to be again dissipated in the arc as often as the current may pass the zero.

As a design departure intended to comply generally with the demands of a good breaker, as implied in the foregoing, the resistance breaker (Fig. 3) was developed. Briefly, the operation of this breaker, by a number of steps, introduced a resistance into the circuit sufficient to limit the current to a value readily ruptured. The fundamental idea was to reduce the enormous short-circuit currents to values which could be opened with certainty by an ordinary breaker. The principle is an excellent one but the accomplishment is difficult for several reasons, some of which are: the fundamental fact that resistance absorbs real energy, becomes heated, and in case of delayed operation of the breaker may be destroyed; the necessary contacts and insulation for such a resistance form a serious problem. There are also mechanical forces to be dealt with. The substitute for resistance in such an application is reactance, and reactance is now used for the purpose.

The general scheme of the reactance breaker differs from the

resistance breaker illustrated, in that but one step is used to introduce the whole reactance, also two sets of contacts are used: one a main heavy set of contacts which regularly carry the load current, and the second an auxiliary set which only carry the reduced current after the main contacts have opened and thus

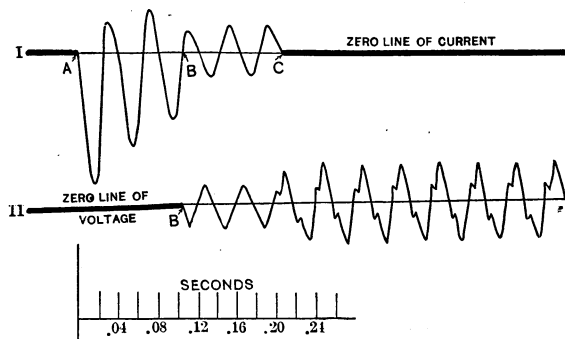


FIG. 4.—OSCILLOGRAM ILLUSTRATING OPERATION OF REACTANCE BREAKER TAKEN ON A 12,000-VOLT SYSTEM.

Maximum current of approximately 16,000 amperes reduced (at "B") to approximately 3000 amperes by the introduction of reactance.

introduced the reactance into the circuit. The auxiliary contacts rupture the final current when they separate and are also first to make contact when closing the breaker.

The design of a suitable reactance coil involves a knowledge of the maximum current which the breaker will be required to

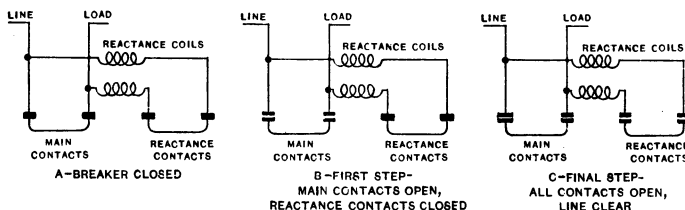


FIG. 5.—CONNECTIONS ILLUSTRATING OPERATION OF REACTANCE BREAKER ILLUSTRATED BY OSCILLOGRAM, FIG. 4.

rupture, the potential and frequency of the circuit, and the time which the reactance coil may be required to carry the maximum short-circuit current which the system can deliver through the coil. A coil properly designed according to these data will limit the currents to desirable values and carry, with a good margin,

the maximum short-circuit currents for periods which will never be exceeded in the normal operation of the breaker. The size of conductor in such reactance coils is small, compared with that normally required for the currents involved, because of the short times during which the reactance is in service.

Analysis of test results and theoretical considerations indicate that the reactance breaker properly designed is adapted to any possible power and class of service. This is due to the readiness with which the current-limiting reactance can be introduced into

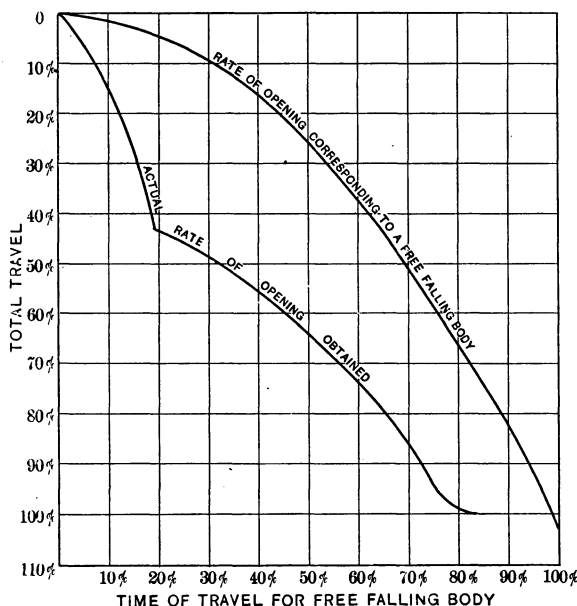


FIG. 10.—CURVE SHOWING RATE OF OPENING HIGH-ACCELERATION BREAKER.

NOTE: 40 per cent of travel, which is required to rupture heavy load, is approximately four times as rapid as that of a free falling body.

the circuits carrying enormous currents, which are thereby reduced to values easily within the rupturing capacity of the breaker.

The resistance breakers have the apparent requisite of absorbing true energy. The reactance breaker does not, and it was at first feared that on some systems the reactance breaker might cause resonance, but a very careful analysis covering a very wide range of conditions indicates that the probability of resonance from the use of reactance is so slight that it may be

called nil. The oscillogram, Fig. 4, and the diagram, Fig. 5, illustrate the operation of a reactance breaker. These breakers have already been built for a number of voltages ranging from 15,000 to 110,000 volts, as illustrated in Figs. 6, 7 and 12, and may obviously be built to meet any requirements. In general, they are to be recommended for circuits where plain breakers are no longer adequate, where the capacity is so close to the ultimate limit of the plain breaker that it is not desirable to take the chance, or where future extensions will require them.

Referring again to the ideal breaker for heavy powers with its high rate of operation, the seriousness of this requirement is more impressive at the extra high potentials, for under these conditions the necessary dimensions required for insulation purposes make rapid operation a difficult matter, even though the current volume may not be large. Practically all high-potential oil breakers built up to the present time have been slower in opening than a free falling body, owing to the friction in their mechanisms. An entirely new design built for heavy service at extra high potentials and having a remarkably rapid rate of operation is illustrated in Figs. 8 and 9. The desirable feature of a high rate of rupture, especially during the fore part of the stroke, is particularly worthy of note. (See Fig. 10.) Actual rupture will, except perhaps in the most extreme cases, occur in less than 40 per cent of the total stroke and at an average rate nearly four times as rapid as attained by a free falling body traveling the same distance. This breaker withstood an insulation test between terminals (open) of over 400,000 volts for a minute, and a like test (closed) between terminals and ground. An idea of the size of this unit, Fig. 9, may be obtained from the following data: height to tip of terminals, 16 feet; floor space, three poles, 24 by 18 ft.

Outdoor breakers have been available so long that it need only be said that the question of protection from the elements has had ample time for demonstration and the problem may be considered solved for all classes of service.

To summarize, breakers for moderate powers and voltages have been well standardized as to design and rupturing capacity. Broadly, the whole subject has developed exceedingly in the past two or three years. Now each individual problem can be definitely and economically prescribed for, and breakers for any power and voltage, indoor and outdoor, are available with all the usual methods of operation, both as to closing and tripping.

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