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HIGH-VOLTAGE TRANSFORMERS AND PROTECTIVE AND CONTROLLING APPARATUS FOR OUTDOOR INSTALLATION

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Outdoor or weatherproof transformers for ordinary distributing purposes, and for potentials up to about 2500 volts, have long been in general service. With the exception of arc lamps and series incandescent lamps, transformers have been about the only apparatus in high-tension service not protected by buildings. Distributing circuits operating at 6600 volts are now quite common. There are also a few 10,000-volt, and a small number of 15,000-volt, distributing systems using outdoor transformers.

Thus far, about 50 kilovolt-amperes has been the limiting capacity found in outdoor service, but there are a few exceptions. Outdoor transformers of 100 kilovolt-amperes capacity or greater, for any voltage, have been almost unknown. Recently, however, large transformers have been taken up; a few are in service, and most of them but for a short time.

The outdoor problem may be divided into two parts:

1. The production of satisfactory outdoor apparatus.
2. The application of outdoor apparatus.

The design and construction will be discussed, and the application will be considered.

Construction. Transformers for outdoor service may be built for any requirements that the ordinary indoor type of oil-insulated unit will satisfy. As to capacity, the limit of approximately 500 kilovolt-amperes will apply to the self-cooled type, depending somewhat on voltage and frequency. As with the self-cooled indoor transformers, the case is the principal problem. It is difficult to obtain the radiating surface required for cooling very large transformers, and still retain a simple mechanical construction. Oil-insulated, water-cooled, outdoor transformers can be built for any capacity irrespective of voltage and frequency.

The first problem apparent in the development of out-

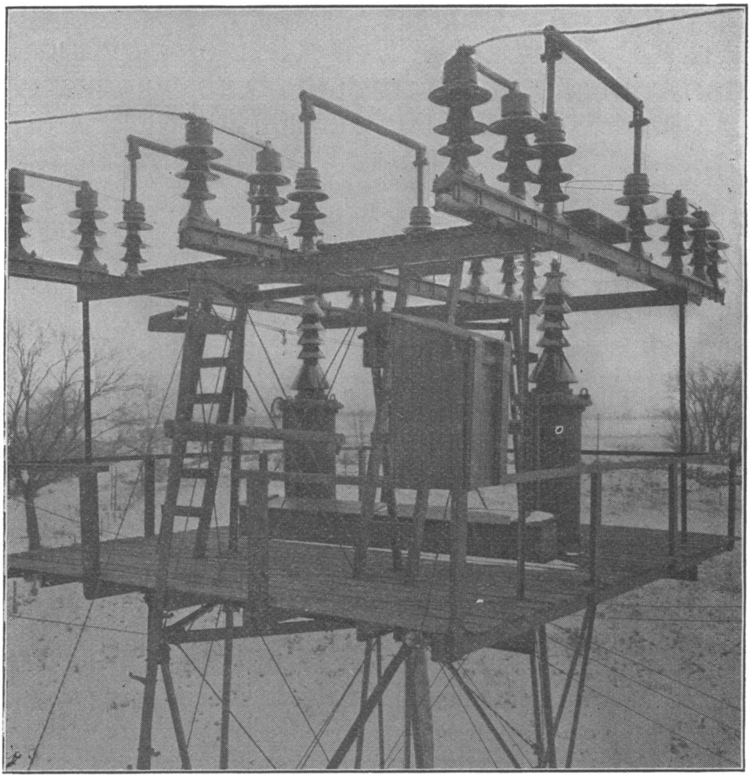


FIG. 1—Two 60,000-volt outdoor series transformers.

door transformers concerned the terminals: how to make them reliable in all kinds of weather and service. The next problem was to weatherproof the case satisfactorily. This much of the problem has been worked out, and now outdoor transformers up to 500 kilovolt-amperes capacity have been built, and units for potentials up to 60,000 volts are in service.

The downward projecting lead which issues from an overhanging pocket near the top of the transformer case is a quite satisfactory construction for moderate potentials. 10,000 volts or more can better be carried by upward projecting terminals, this arrangement being particularly attractive for convenience in wiring. About the same practice for placing outlet terminals serves for both indoor and outdoor transformers, so far as the general arrangement and convenience are concerned. The essential requirements of outdoor terminals are that they

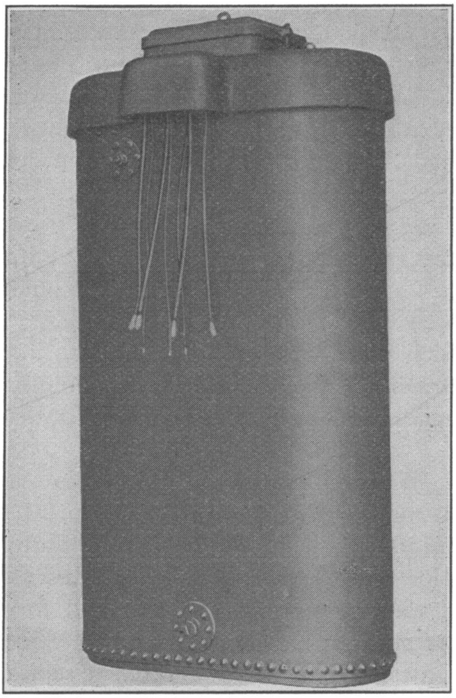


Fig. 2—This construction for outdoor service has been used for 6600-volt 25-cycle, three-phase transformers from 75 to 350 kilovolt-amperes.

retain their insulation characteristics and that they do not deteriorate by exposure to the elements. Outdoor terminals are larger and require much more room than those for indoor service.

Fig. 11 illustrates a self-cooled, 300-kilovolt-ampere, 33,000-volt, outdoor unit. The case is of corrugated sheet-iron with welded vertical seams. The bottom and top are cast on the corrugated shell. The resulting construction is strong, oil-tight, and is not subject to damage by the elements. The cover, also of cast iron, has a considerable overhang or eave to guard the joint between it and the top of the case, and is fitted with the outlet terminals and a small inspection door. All joints are protected by an overhang and are designed for making tight with gaskets.

Outdoor water-cooled units employ the same general construction as the self-cooled type, except that the cases will usually be of boiler iron, and cooling coils with connections must be provided.

Weatherproofing outdoor transformer cases is doubtless best done by making the joints vacuum-tight. Eliminating leaks means that nothing can enter, and therefore a clean, dry unit would remain in that condition. Moisture is the only enemy to be feared, either in the form of rain, snow, or humidity. The "breathing" of wet air is the most important source of trouble. because it is the hardest to eliminate. As a transformer heats, part of the air in the top of the case will escape if an outlet exists and new air will return as the initial temperature is resumed. Under certain conditions moisture which may have entered with the new air will condense. The amount of moisture which will accumulate in this way, in a short time is quite surprising. Well-made gasket joints, with deep, overhanging eaves and carefully sealed-in outlets, give good results.

Application. Whether outdoor apparatus is really desirable, involves a great many points even after it is proved satisfactory in the individual piece. Some of the more important considerations are: location and climate; cost of building and ground for indoor station; cost of corresponding ground for outdoor station; capacity of station; high-tension and low-tension voltages; number of high-tension and low-tension circuits; method of operation and control; method of cooling; attendance and supervision; instruments and their housing; and the cost of indoor versus outdoor apparatus.

A 20-kilovolt-ampere, 2200- to 220-volt transformer immediately suggests a pole installation. But if the figures are multiplied by ten, a 200-kilovolt-ampere, 22,000- to 2200-volt transformer suggests indoor service. If these figures are multiplied by three, a 600-kilovolt-ampere, 66,000- to 6600-volt transformer certainly has always demanded housing.

The large clearance required for exposed high-tension wiring and disconnecting switches; the expensive construction demanded for enclosed high-tension wiring and switch structures; the cells or compartments often used for transformers; the space for protective apparatus—all these operate to make the high-tension station costly as compared with the low-tension station. If all high-tension apparatus were placed outside, some kind of a structure would still be required in most cases for housing the instruments, the high-tension control apparatus, and the low-tension switchboard. If attendance were contemplated, some additional facilities might also be required. Under nearly all conditions where control of either or both high- and low-tension circuits is demanded, some housing will be required. Attendance, or at least frequent inspection, should usually be provided. When housing is needed for part of the apparatus, perhaps a large part, the expected advantage of placing the remaining apparatus outdoors may not become important, or may even not exist at all. In order to obtain the cost comparison, the cost of the station grounds and indoor apparatus must be balanced not only against the smaller building, but also against all the ground required for the outdoor apparatus, the outdoor apparatus itself, and the instruments and the indoor control apparatus.

If the high-tension circuits are many, and switching is contemplated, the outdoor arrangement appears attractive. If the low-tension plan calls for the control of the several circuits, the indoor arrangement looks desirable, as but little additional indoor space over that required for the instruments and high-tension control panels may be necessary for the low-tension switchboard. Furthermore, indoor low-tension switches and wiring, especially if remote control be not used, should be cheaper. Finally, when there has been provided a house that covers all but the high-tension pieces, it may be found that a small additional cost would have housed everything. Evidently no rule can be set down, as every case will require individual solution.

With all the large bodies of oil in such apparatus as the transformers and circuit-breakers outdoors and only instruments and remote-control boards indoors, the life and property hazard may be considered as less than in the equivalent but more congested indoor arrangement. The likelihood of careful inspection, however, is also much less, especially in bad weather. The difficulty of outdoor repairs except in the finest weather, is worthy of attention; though failures are very infrequent with well-built high-tension apparatus.

The successful outdoor transformer would itself be of less interest if outdoor switches and protective apparatus were not also available. Under such conditions, omitting the housing for the transformer might be of small advantage if protection for all other apparatus were still to be provided. The economy

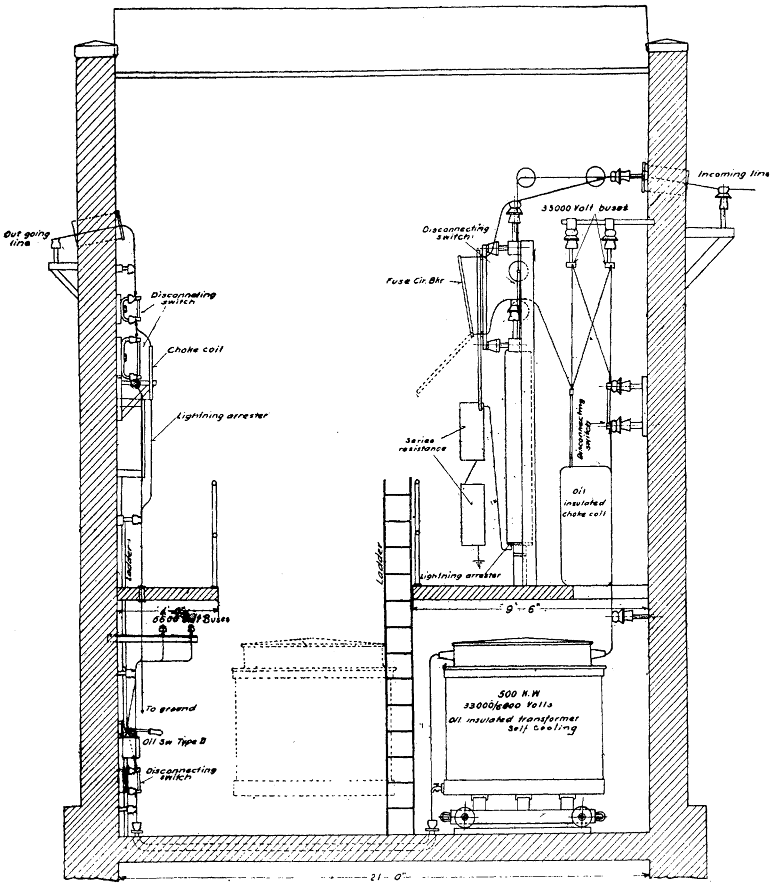


FIG. 3—Sectional view of 1500 kilovolt-ampere, 33,000-volt to 6600-volt, 25-cycle transformer station.

anticipated from employing outdoor transformers can generally be but partly realized without other outdoor apparatus.

Fig. 3 shows an indoor 33,000-volt station and Fig. 4 shows an equivalent outdoor station, No instruments are employed and no attendance is required. The station is entirely without a building. Fig. 5 shows a 60,000-volt indoor station, and Fig. 6 shows an equivalent outdoor station of one-fourth the capacity. As an example of the growth toward outdoor stations, there may be cited the Lockport station of the Niagara, Lockport &

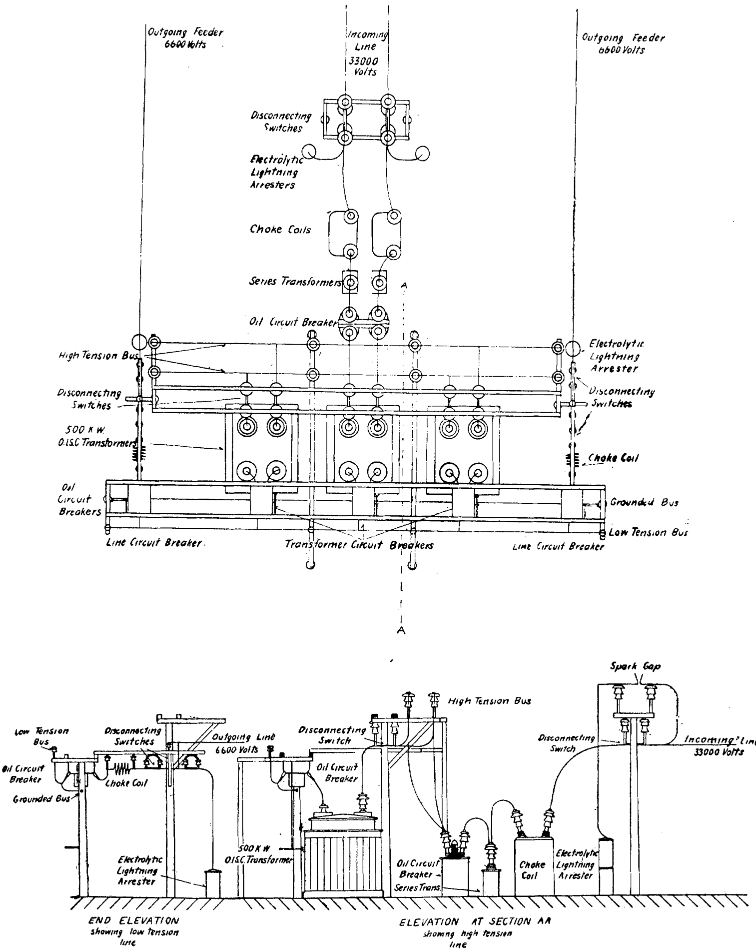


FIG. 4—Illustrates an outdoor transformer station equivalent to the one shown in Fig. 3.

Ontario Power Company. Some of the illustrations of this station showing outdoor lightning arresters and 60,000-volt busbars have already appeared in the Institute TRANSACTIONS.*

Considered purely as a circuit-interrupting device, whether

* Transactions A.I.E.E., 1907, Vol. XXVI, Part II, p. 1273.

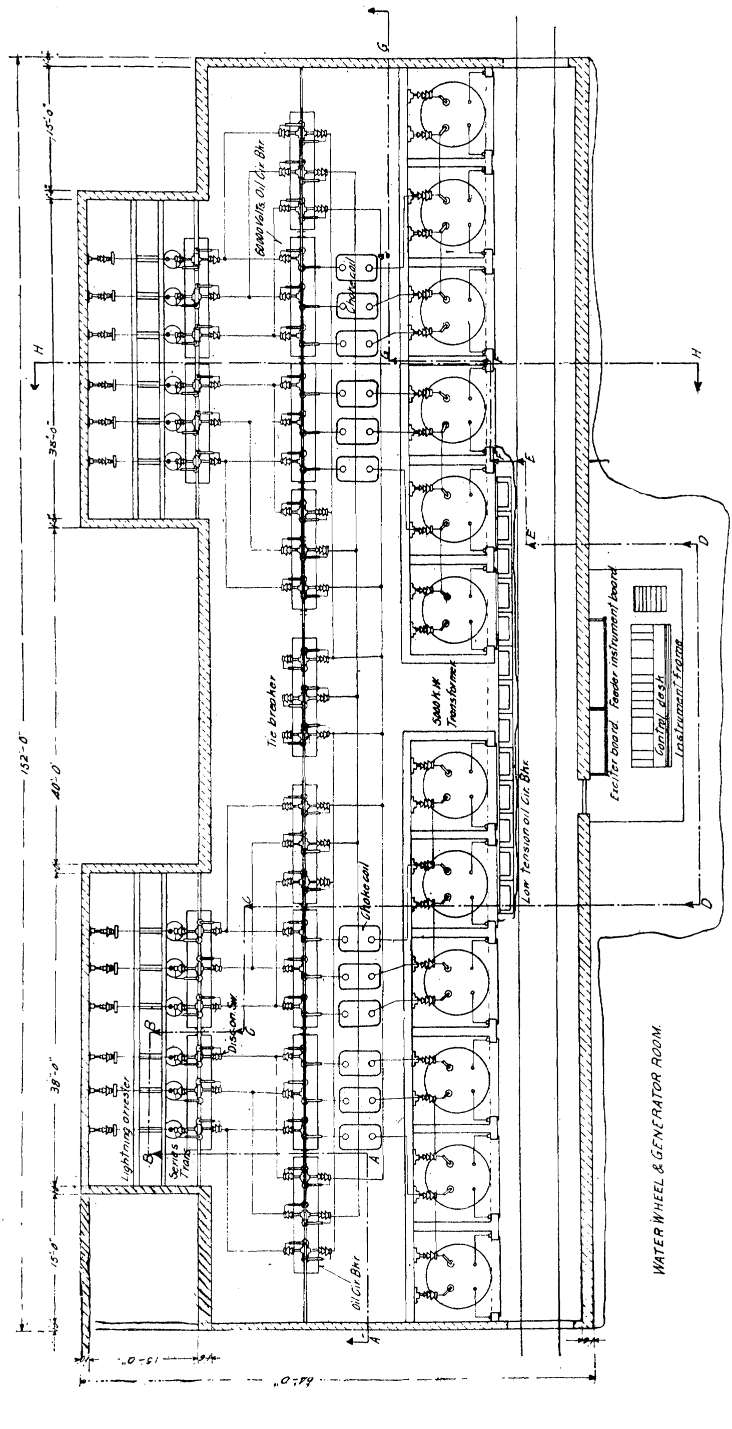


FIG. 5—Plan of 60,000-volt, 60,000-kilovolt-ampere, indoor transformer station.

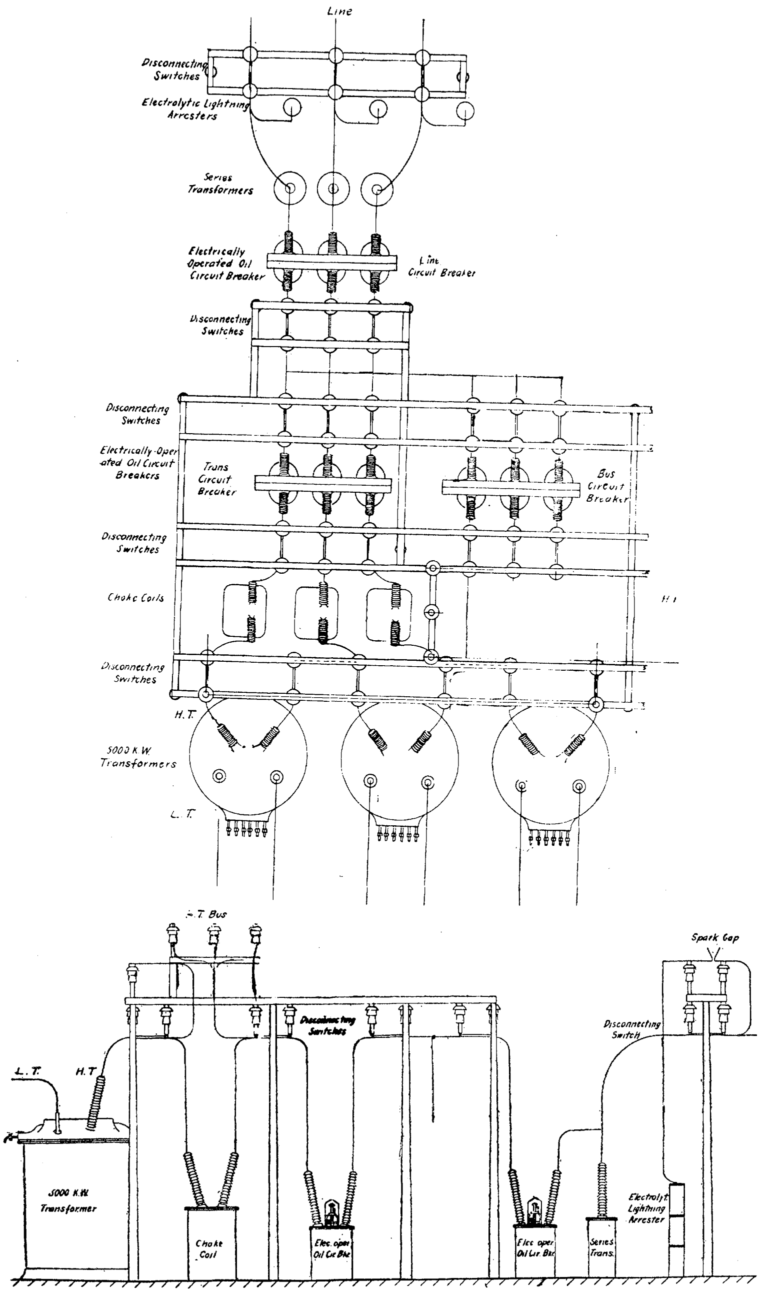


FIG. 6—Layout for outdoor transformer station, equivalent to one-fourth of indoor station, Fig. 5.

a circuit-breaker operates indoors or out does not affect the requirements. Outdoor transformer construction will take care of case and terminals—a suitable enclosing hood readily removable to protect the mechanism from the elements, snow and ice particularly, completes the changes necessary to make an outdoor unit. Non-freezing oil should be used in order that operation in severe weather may not be endangered. The ordinary methods of operation such as remote control, overload release, etc., are available just as in indoor practice. Outdoor disconnecting switches are in common use, and outdoor fuses have also found favor in some places.

The horn-gap arrester has been used considerably in outdoor service, both at terminals and along the transmission line, and the electrolytic type has been installed both indoors and outdoors. Arresters for all transmission voltages and designed for outdoor use are now available. The considerable amount of space indoors required for high-voltage lightning-arresters, and its cost, are serious; in fact, arrester houses are not unknown. Outdoor types may therefore be of particular and almost independent interest.

Outdoor choke-coils differ from indoor choke-coils only in respect to case and terminals; if of the oil-insulated type, the outdoor-transformer construction will apply. It is noticeable that about the same structural problems and solutions apply to outdoor transformer circuit-breakers and protective apparatus.

It has been suggested that by treating the high-tension transformer as part of the line, no high-tension circuit-breakers would be required and no high-tension lines need enter a building. All switching would be done on the low-tension side, and when necessary fused disconnecting switches on the high-tension side would serve to cut off the transformer.

Outdoor stations should be paved and well drained around the apparatus. If this is considered too costly, individual foundations for each piece will serve. Transfer trackage with a truck, or a heavy hand truck will be found very convenient when moving apparatus.

When the stations are important it will usually be found desirable to arrange a room with repair facilities and connected with the outdoor station trackage, rather than resort to temporary weather protection or to remove the apparatus to a distance, should repairs be necessary. Such space would doubtless be convenient for many purposes such as cleaning and inspecting. Fencing, to keep out intruders, is advised when more than the bus-bars are outdoors.

The general use of outdoor apparatus to the exclusion of indoor apparatus is, of course, not to be expected; but frequent

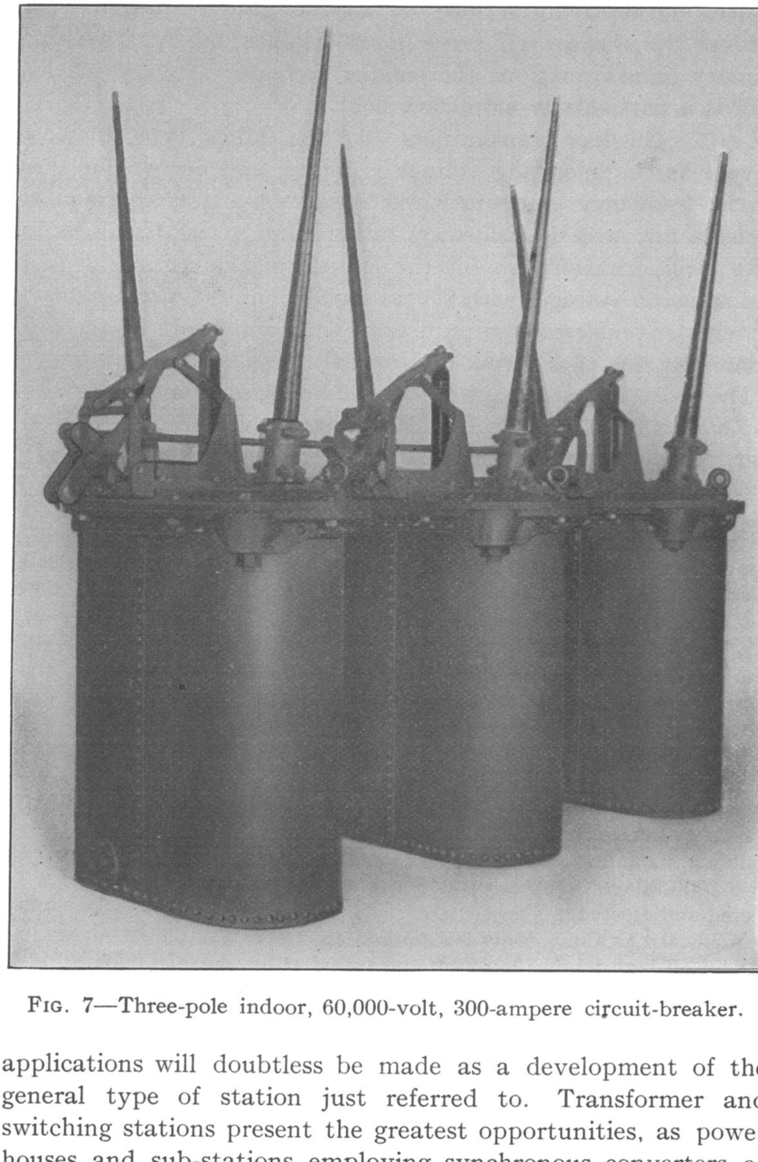


FIG. 7—Three-pole indoor, 60,000-volt, 300-ampere circuit-breaker.

applications will doubtless be made as a development of the general type of station just referred to. Transformer and switching stations present the greatest opportunities, as power houses and sub-stations employing synchronous converters or motor-generator sets require so much housing that indoor transformers, circuit-breakers, etc., may be considered best.

If power is to be used within a short distance of a transmission line, a single transformation to the service voltage will be best. When an extended distribution is to be fed, a secondary transformation to the service voltage should be employed. The outdoor transformer will serve in either place, but with existing primary transformations the smaller secondary transformation affords a particularly attractive field.

Costs. Outdoor transformers, like the indoor type, increase in cost as the operating voltage is raised, and decrease in cost as the frequency of operation is increased. It is common to prefer a few large transformers rather than several small units. Also large transformers for the transformation from the high transmission voltage, with several smaller units on a secondary system, are preferred to a number of small units serving the consumers by one transformation from the transmission voltage.

The following cost estimates based on existing installations—two equivalent indoor and outdoor 2000-kilovolt-ampere, 25,000-volt, 60-cycle stations—may be of interest.

Indoor station. High-tension apparatus inside of building. Transformers in pockets.

Approximate cost of steel building. frame erected	$3100
Inside of building, including steel work	2300
Total for building	$5400
Two 1000 kilovolt-ampere, three-phase, 22,000-volt to 440-volt, 60-cycle transformers delivered and erected	7200
Switchboard for above, including two incoming line panels step-down transformers' panel, and necessary oil switches	2500
Total for station	$15,100
Outdoor station.	
Building, including outside bus-bar structure	$1020
Two 1000 kilovolt-ampere outdoor transformers as above, delivered and erected	7800
Switchboard as above (only low-tension apparatus and panels inside) all high-tension bus-bars and transformers outside, delivered and erected	2625
Total for station	$11,445

From these figures, the indoor station costs approximately 30 per cent more than the outdoor station.

Another example covers the approximate costs of a 3000-

kilovolt-ampere, 22,000-3000-volt, 25-cycle motor-generator sub-station.

Indoor station. Incoming lines 22,000 volts, two of which are installed. Building structural steel, all apparatus inside, transformers in brick compartments. High- and low-tension bus-bars and oil switches in compartments.

Length of building 110 ft., width 38 ft., equalling 4180 sq. ft.	
Approximate cost of building ready for apparatus, steel work and compartments	$21,835
Three 1000-kilovolt-ampere, three-phase, 22,000/3000 volt, 25-cycle, step-down transformers, delivered and erected	15,000
Three 1000-kilovolt-ampere, motor-generator sets, motor synchronous type, 3000 volts operating at 80 per cent leading power-factor. Generator 550/600 volts, delivered and erected	48,000
Three 45-kw. exciters, induction motor driven, delivered and erected	4,500
Two incoming lines 22,000 volts, three-phase.	
Three three-phase 1500-kilovolt-ampere, step-down transformers panels 22,000/3000 volts.	
Two three-phase railway feeder panels 3000 volts, 3000 kilovolt-amperes.	
Four three-phase lighting feeder panels, 3000 volts, 500 kilovolt-amperes.	
Three panels for controlling motor-driven exciters.	
Three synchronous motor panels.	
One direct-current feeder and total output panel 600 volts, 3000-kilowatt switchboard delivered and erected	20,000

Recapitulation.

Building	$21,835
Switchboard	20,000
Transformers	15,000
Motor-generator sets	48,000
Exciters	4,500
Total cost	$109,335

Outdoor station. High-tension apparatus outdoors on concrete foundations. Building to be 110 ft. by 19 ft. Station same as above as regards output. Ordinary type of building. No steel work.

Building	$7,480
Switchboard, same as above. Oil switches made weatherproof	20,200
Transformers made weatherproof	16,000
Motor-generator sets as above	48,000
Exciters, as above	4,500
Total	$96,180

In this example, as might be expected, the saving of approximately 13 per cent is not so large as for the simple transformer station.

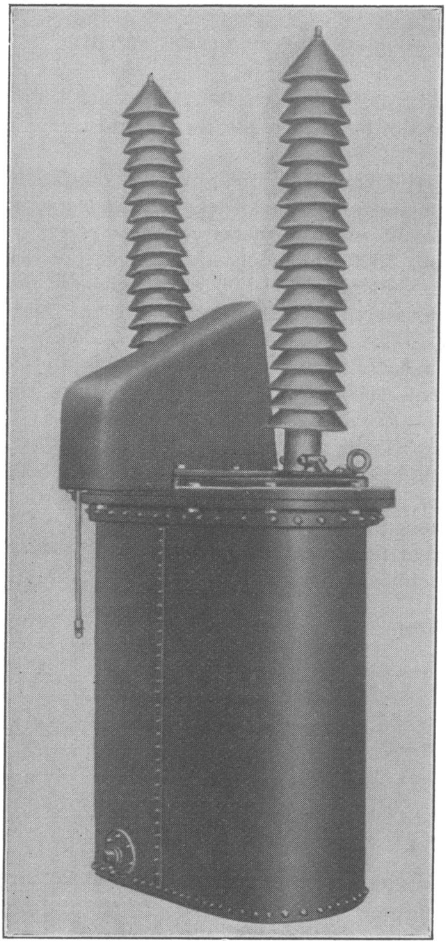


Fig. 8—Single-pole, 60,000-volt, 300-ampere, outdoor breaker. (This is one pole of three-pole indoor breaker, Fig. 7, arranged for outdoor service).

Service. For outdoor transformers the same care is required as for indoor transformers. An occasional test of the oil as obtained from the sampling pet-cock should be made. If attendance is at hand the usual load and temperature log should be kept. This applies to self-cooled and water-cooled units just as in indoor practice. Thorough and detailed inspections should be made at such infrequent intervals as the operating conditions would indicate to be desirable.

In the summer, protection from the sun will probably be an advantage, and this may take the form of a simple fence high enough and so placed as to cast a shadow over the transformer

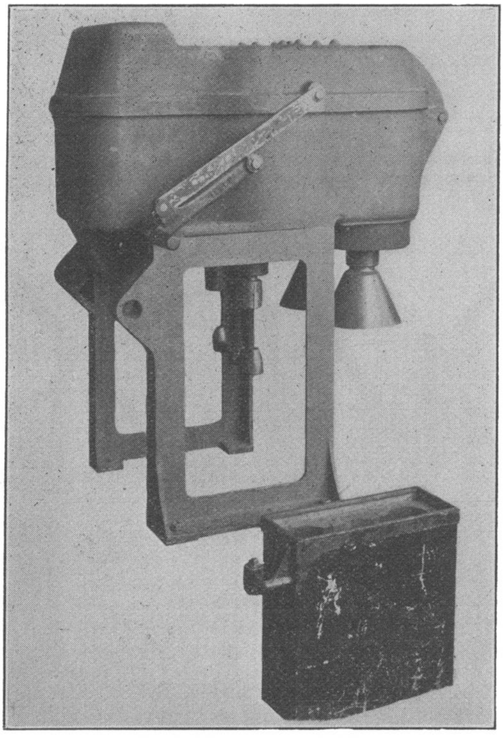


FIG. 9—11,000-volt, 300-ampere, remote-control, automatic, outdoor circuit-breaker.

during the hottest hours of the day. At night the cooling conditions will be much more favorable, and the heat accumulated during the day will be discharged, so that each day is started with a cool transformer. The large amount of oil in self-cooled transformers represents a great thermal capacity; it acts as a sort of flywheel for the system, tending to smooth out temperature fluctuations.

Water-cooled units do not require shade, and if attendance is at hand their temperature can be held practically constant under varying load and weather conditions, if desired, even without automatic thermostatic control of the cooling water.

In extreme winter weather, if the transformer is likely to be shut down for a considerable time the cooling coils should be freed of water so that they cannot freeze and burst.

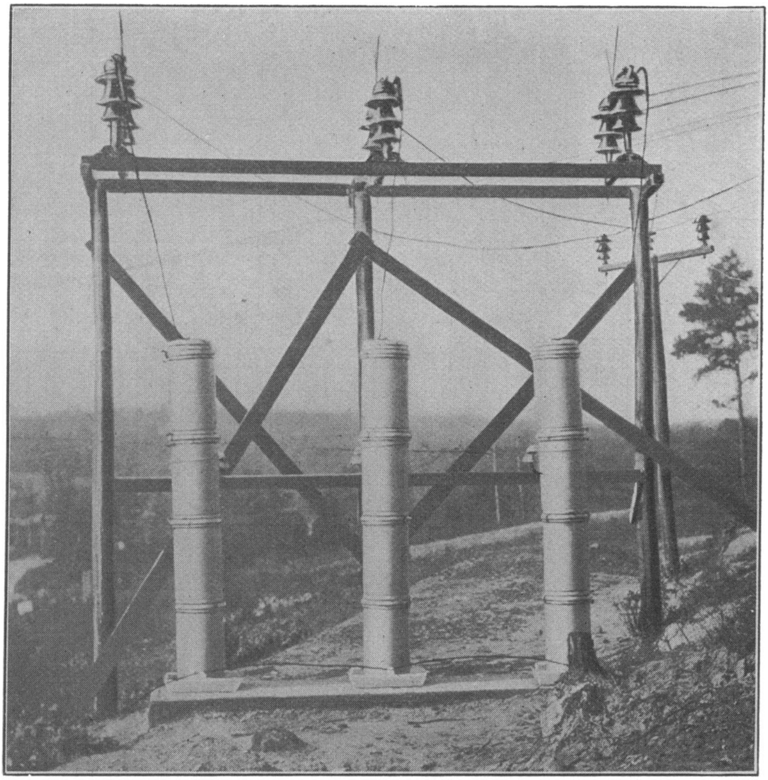


FIG. 10—Outdoor installation of 50,000-volt, electrolytic lightning-arresters.

Transformer oil will thicken at about 0° cent., but does not harden so as to damage windings or case, as freezing water might do. When cold as this the insulating quality of the oil is reduced, but not so as to make it unfit for its purpose. In ordinary service such conditions need not arise, as the iron loss alone will usually suffice to keep the oil fluid. In extreme weather conditions, self-cooled units may be kept warm by screening with a tarpaulin, thus reducing the effectiveness of the cooling surface. Similarly, the water-cooled unit may be operated without water, or with very little, to accomplish the same results. In some instances it may be found desirable to lag the water supply pipes during cold weather.

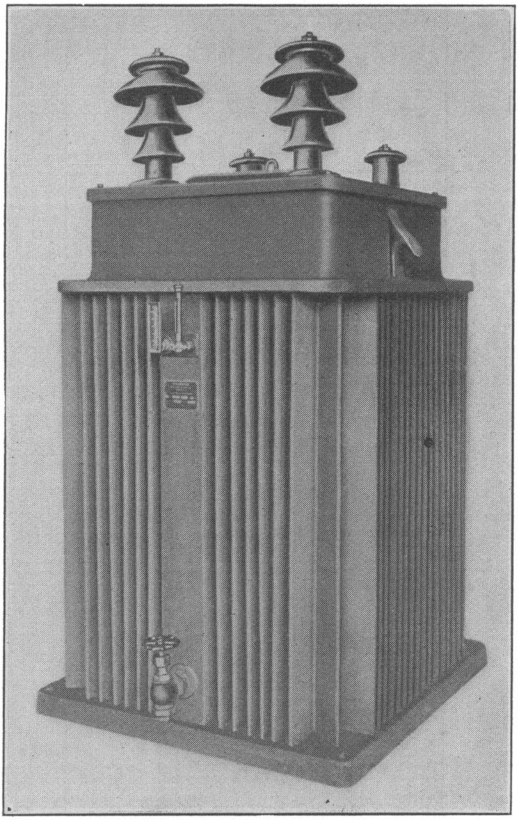


FIG. 11—300-kilovolt-ampere, 33,000/6600-volt, 60-cycle, oil-insulated, self-cooled transformer. (Illustrates general construction for outdoor transformers of moderate capacity).

A self-contained sub-station made up of transformers, circuit-breakers, and choke-coils has been proposed. Such an arrangement, if three-phase, would require but three high-tension leads and would dispense with of twelve other leads otherwise required by switches and the choke-coils. If the choke-coils are omitted, six leads are still saved. For capacities up to approximately 250 kilovolt-amperes this arrangement may be found attractive. Such units should be protected by fuses or other circuit-inter-

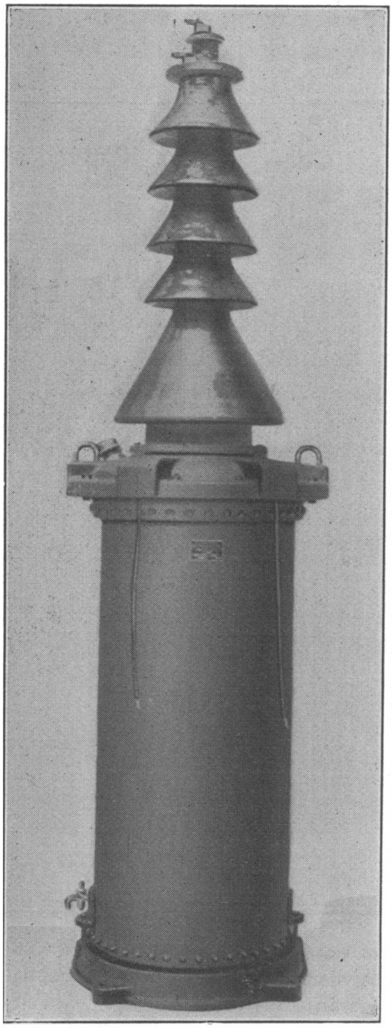
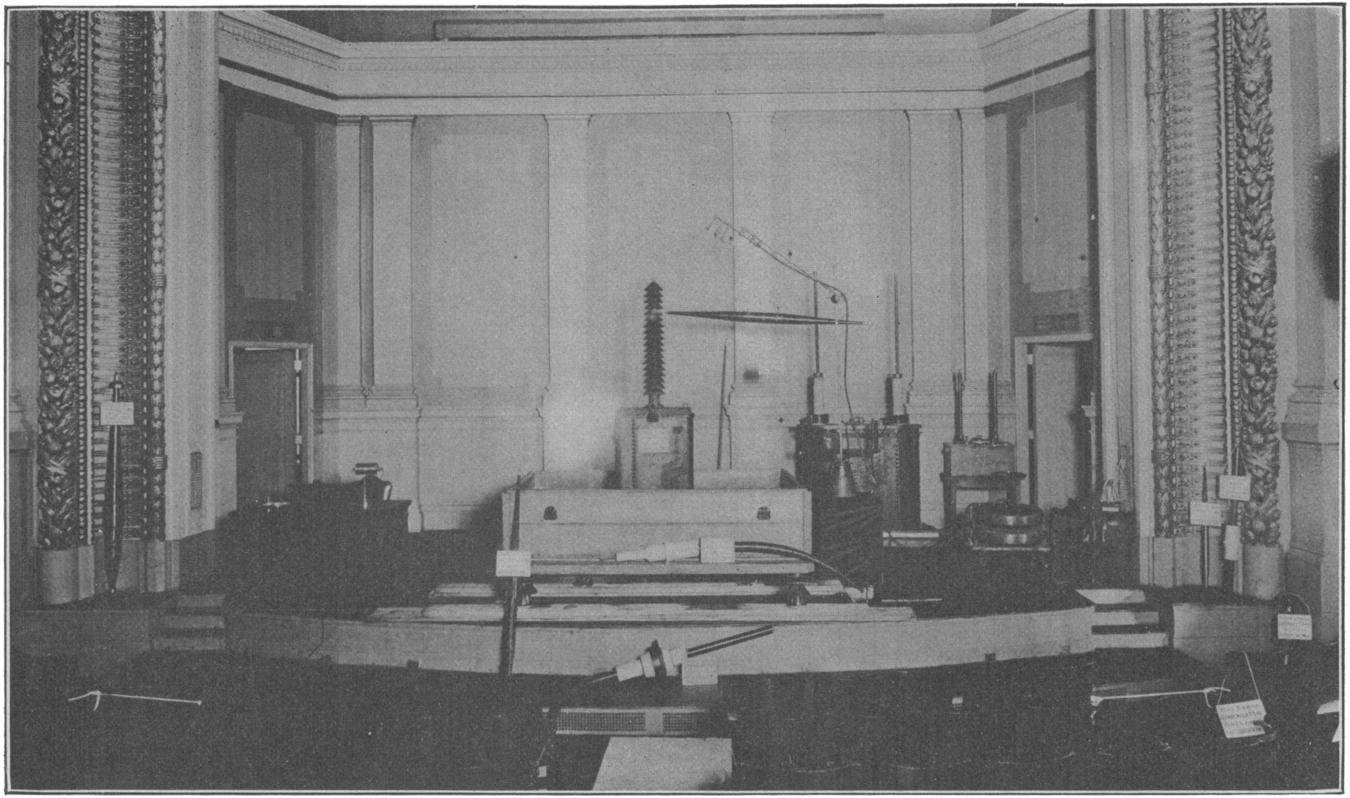


FIG. 12—60,000-volt, outdoor series transformer. (Fig. 1 shows two of these transformers installed).

rupting devices on the high-tension side, as a failure outside of the switch could not be relieved by it. Disconnecting switches should also be used.

A construction which permits of shipment in the case with oil is an improvement in transformer design which has been received with quite general favor, as the installation problem is much simplified. The usual unpacking, reassembling, and drying out, if necessary, is reduced simply to removing the blind flanges from the terminal openings and replacing the terminals in order to be ready for operation. Transformers arranged for shipment in their cases with oil, if made weatherproof, need never enter a building after leaving the factory, unless repairs or inspection should demand it.

Summary. The advantage of outdoor apparatus lies in cheapening the installation, due to a saving in building; there is also less life and property hazard. The disadvantages are absence of protection from weather when inspecting, overhauling or making repairs, and exposure to molestors. The problem, as a whole, was, first the transformer; second, the switch; and, third, the protective apparatus. All of these have been worked out and some experience obtained. The problem now is to decide when outdoor apparatus is warranted. This is a question of the station rather than the apparatus, and is subject to the individual conditions of each case.



Apparatus used for testing condenser type of insulation for high-tension terminals to 225,000 volts
Auditorium of the Engineers' Building, New York, April 9, 1909.