

place of insulation, which might otherwise be used. I may say here, however, that whenever air is used some means is always supplied by which the air is circulated through the windings, thereby cooling as well as insulating the transformer. In the case of oil insulation this does not necessarily apply, as in small units and up to say 500 k.w. there is no provision made for outside cooling.

The air insulation transformer is generally speaking more correctly called the "air blast" transformer, in as much that air under pressure of about $\frac{1}{2}$ ounces per square inches is used for cooling purposes. The insulation in this type consists mainly of cloth, paper, film, and wood, each and all of which are impregnated with oil or varnish.

Spaces or ventilating ducts are left between the coils for the free passage of air used for cooling purposes, and these passages act in the same manner as if they were filled with insulating material, such as oil, until a certain voltage is reached, when static discharges across the high tension coils take place. The usual range of operation of this type is up to 20,000 volts and the maximum is about 35,000.

When we use oil as an insulating material we have a wider range of voltages, the maximum running almost as high as we like to make it, and easily as high as the present day transmission line will permit.

The method of using oil as an insulating material in the transformer of the present day is simplicity itself. The windings, properly dried, are simply placed in the case and covered with oil. This oil insulates the winding from each other, from parts of the case; keeps them dry and also cools them by carrying heat generated in the coils and core to the case.

FIRE RISKS.

We might now consider briefly the fire risks of the two methods of insulation. To show the difference of opinion on this important branch of the subject we will quote the following:

"In both types the insulating material is of an inflammable nature, and under certain abnormal conditions may take fire with more or less serious consequences.

"The electrical engineer must, therefore, consider carefully not only the relative, but the actual fire-hazard which exists, and by proper and common-sense methods minimize such danger. Both types can be made entirely safe by correct methods of design and installation.

"I think it will be admitted that in general that type which contains the greater quantity of inflammable material will occasion the greater fire-hazard. The inflammable material in an air-blast transformer of say 1,000 k.w. capacity, will amount to about 800 pounds; in an oil-cooled transformer of the same capacity the amount will be about 7,300 pounds. While this comparison cannot be taken as a measure of the relative fire-risk, it is an indication to be considered, especially in view of the fluidity, the low temperature of ignition, and high calorific value of oil.

"While the quantity of inflammable material in an air-blast transformer is, as stated, relatively small, it has an extended surface exposed to a large volume of air, and therefore, if a fire starts from internal causes, such

as short circuit or extreme over-load, is capable of rapid combustion. This combustion could be checked by shutting off the flow of air to a transformer by means of a diaphragm automatically closed by the melting of a fusible link, the fusible link so located as to be melted by the first contact with flame; a method similar to that employed for closing fire-doors in buildings.

"An oil transformer properly cooled is probably not particularly subject to ignition of the oil from internal burn-outs or arcs. It is well known that oil is an excellent medium for the smothering of alternating arcs, and this principle is utilized in connection with oil-switches. The vapor above the oil, may however, be ignited by electrical discharges. Even in this case, while the quantity of combustible material is enormous, the surface exposed is relatively small. The principle fire-hazard in an oil transformer is due to the large mass of inflammable liquid material which under certain conditions may become totally consumed. It becomes a special hazard in the case of fire from sources external to itself.

"Considerations of first cost, economy of space, simplicity, operating costs, etc., have resulted in placing transformers in the same room with switchboards and other apparatus, such as synchronous converters, motor-generators, etc. Under such conditions, it would seem that the air-blast transformer constituted the lesser fire-risk than the oil transformer, and would therefore be generally employed if the fire-risk were the only consideration. The air-blast type, however, is limited in practice to pressures of about 30,000 to 35,000, as the static discharge which occurs at much higher pressures would in time break down the insulation. It is therefore necessary to employ oil insulation on the higher pressures now common.

"The fire-risk can be practically eliminated by placing such transformers in a room or rooms separated by suitable fire walls from the other part of the plant. This plan has already been proposed and introduced. An entirely separate building, sub-divided again into suitable rooms, may be employed where the maximum of safety is demanded. Much may be done to limit the risk, even when the transformers are placed in the same room with other apparatus, by proper systems of piping and draining the oil away from the building, by placing the transformers in a depressed area of concrete arranged for rapid drainage, etc. Of course any of the methods commonly employed for preventing, limiting, or extinguishing oil fires may properly be employed."

This article by E. W. Rice, jr., gives the oil insulated type the greater fire risk principally on account of the greater amount of combustible material in the transformer case itself. Now referring to an article by J. S. Peck, in Vol. 2 of the same work we have the following:

"During the past year, a considerable amount of discussion has occurred regarding the relative fire-risks of oil-insulated and air-blast transformers. The general results brought out seem to indicate that so far as actual damage to the transformer itself is concerned, either by internal or external heat, the risk is much greater with the air-blast

transformer than with the oil-insulated type. The greater risk of the air-blast transformer results, not only from the more inflammable nature of its insulation, but also on account of the presence of the air blast, which tends to increase the rate of combustion, as well as by the open construction necessitated by the method of cooling.

"In the oil-insulated transformer, the oil cannot be ignited unless it is first raised to a very high temperature. Oil also acts as an extinguisher of arcs which occur below its surface, and, if the transformer is inclosed in a tight case, the oil, even if ignited, cannot continue to burn, on account of lack of fresh air.

"There is, however, a danger incident to the operation of the oil-insulated transformer which is due to the fact that oil-vapor, when mixed with the proper proportion of air, forms an explosive mixture, which, becoming ignited, may burst the containing case and permit the oil to escape. With large transformers it is now customary to use a practically air-tight case, sufficiently strong to withstand an internal pressure of approximately 100 pounds per square inch, which is probably in excess of any pressure that can actually be obtained. In large transformer installations, each transformer, or each group of transformers, is often placed in a vault or pit, which is properly drained and, in the event of a case being damaged by external causes so that oil escapes, it will not spread about the station floor, but be carried away by the drain.

"With every precaution taken, the presence of large quantities of oil must constitute a certain fire risk, and for this reason it has become the general practice to specify air-blast transformers for use in sub-stations which are located in thickly populated portions of large cities. Such transformers are usually wound for 6,000 to 15,000 volts, for which pressures the air blast transformer is well adapted. For very high voltages, it is of course necessary to use oil-insulated transformers, taking such precautions in their installation, as to reduce to a minimum the danger to surrounding buildings or apparatus.

"A method for reducing the fire hazard of the oil-insulated transformer which has been used to a limited extent, consists in placing the transformer in a tight case with a vent-pipe connected to the top of the dome-shaped cover. At the bottom of the case a connection is made with the water-mains, so that, in case of necessity, water can be admitted at the bottom of the case, driving out the oil through the top vent and leaving the case filled with water. The vent may be connected with a sewer, or with a suitable tank for receiving the oil."

This author gives the greater risk to the air-blast transformer for the simple reason that it is air-blast and so tends to quickly spread any fire which might occur in it or its vicinity. However, if the necessary precautions are taken in the installation and the necessary attention given during operation, I agree with Mr. Rice and think that the fire risk can be reduced in both cases to a negligible quantity.

The quality of the oil necessary to use will be discussed under the head of "Cooling."

* "High Tension Power Transmission," by E. W. Rice, Jr., American Institute of Electrical Engineers