

## TERMINALS AND BUSHINGS FOR HIGH-PRESSURE TRANSFORMERS.

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This subject will include cables, straps, connectors, etc., for both high- and low-pressure side, designed both for terminal connections and for changes in the ratio of transformation, together with their insulation. In transformers for moderate pressure and having but two high- and low-pressure terminals, the problem of terminals is a simple one; with higher pressures and numerous changes in the ratio, however, the design of these parts of the transformer often becomes a most difficult problem, upon the proper solution of which depends, to no small extent, the reliability of the transformer.

### LOCATION OF TERMINALS ON COILS.

It is much better to have the high- and low-pressure terminals at opposite ends of the structure, for it is almost impossible to keep safe distances between the terminal and connecting coil leads when all are at one end. In a shell-type structure, having its coils in a vertical position, this requires one set of coil terminals to be at the bottom of the case, but to bring these safely to the top is not as difficult as to separate high- and low-pressure conductors that are at the same end of the windings.

### INSULATION OF TERMINALS ON COILS.

In an oil-immersed transformer, this presents little difficulty, as it is simply necessary to have all leads rigidly spaced a safe distance from each other and from the coils, and covered with sufficient waterproof insulation to prevent any moisture penetrating the coil around the terminals before the oil is put in.

In air-blast transformers, however, the case is different; here all terminals must be covered with an insulation integral with that on the coil itself, to a distance from the coil that provides sufficient surface insulation, even when the lead is well covered with dust and dirt.

Often the dielectric strength of a transformer is materially lowered by allowing the coil-terminals or taps to project beyond the sides of the coils, thus shortening the distance between primary and secondary. "Spreading" the exposed ends of the windings removes this difficulty, except when the terminal comes from a point well within the coil, but introduces a more serious defect, lack of rigidity to withstand the strains of short circuits. Usually the problem can be solved by so winding coils as to have only outside terminals and locating such coils as have taps on the outside of the coil structure.

#### LOCATION OF MAIN TERMINALS.

The best location for these naturally varies with the type of transformer and its pressure; for the air-blast type, the air-chamber forms a convenient and natural location for the low-pressure wiring, and the terminals of these are therefore usually located in the base of such transformers and made accessible by doors in the side of the base. For pressures not exceeding 25 000 volts, the high-pressure wiring can also be placed in the air-chamber, without making the air-chamber of excessive cross-section, so that all transformer terminals are in the base and exposed wiring is avoided. Heavy rubber-insulated cable is to be avoided in such construction, however, for should the rubber take fire from short circuit or other causes a draft of air will carry the fire rapidly along the duct and into the transformers.

In oil-filled transformers the terminals are, of necessity, located at or near the top of the case. Often for convenience in external wiring, projecting pockets are provided through which terminal-leads may leave the case in a downward direction. With such construction, it is necessary to have a solid section in the cable, just above the oil line, and to have this section insulated or covered with an insulation impervious to oil, otherwise the cable and insulation will act as a siphon and discharge oil.

#### INSULATION OF MAIN HIGH-PRESSURE TERMINALS.

Below 40 000 volts, the insulation of terminals offers no special difficulty; porcelain or glass bushings can readily be obtained that are safe for this pressure, even if the conductor

has no insulating covering. For higher pressures, the problem is more difficult. If no insulation is used on conductor, the bushings become expensive and so large that there is scarcely room on top of a moderate size transformer for as many terminals as are often required. The following are some of the more common forms of bushings that have been used:

Wooden tubes;

Hard-rubber tubes;

Glass and porcelain tubes, both single and concentric;

Numerous forms of molded porcelain bushings.

Wooden tubes of the necessary size cannot be thoroughly dried and filled. Hard rubber is so apt to contain impurities that it is unsatisfactory; moreover, it deteriorates rapidly if ozone is generated near it. Glass is fragile and must be protected with other semi-insulators. Porcelain, or any smooth tube, must be very long if it have sufficient leakage surface to be safe when dirty, and even the best shapes of corrugated bushings are large and expensive when capable of withstanding a test of from 75 000 to 160 000 volts. All things considered, the writer has found the following practice quite satisfactory for test-pressures not exceeding 160 000 volts.

Insulate the lead with varnished wrappings that will safely withstand for one minute about half of the test-pressure to be applied, bringing out this lead through a porcelain bushing having the same strength as the insulation of the lead, and sufficient surface to prevent leakage at this pressure when dirty; in other words, let the insulation of the leads be sufficient for the working pressure, and the porcelain be of such strength as to give the factor of safety desired. This combination forms a far safer insulation than a bare conductor and a larger bushing which would stand the same puncture test as the combination, from the well-known fact that oxidized linseed oil is an insulation that will momentarily stand several times as much as it will for any considerable length of time, while porcelain, glass, etc., have no such time-factor.

In leads requiring a test of 100 000 volts or more, and insulated in this manner, an additional difficulty is met in the induced charge on the outer surface of the insulation; at this pressure the surface is covered with a heavy brush discharge that so reduces the surface resistance to leakage that 100 000 volts will travel along several feet. It is usually impracticable to make the insulated lead long enough to withstand the pressure under

these conditions, but the discharge may be broken up, so that it will not appreciably reduce the surface resistance, by bell-shaped pieces of rubber, porcelain, or other insulation slipped over the lead before all the varnished wrappings are put on, and having its small end so shaped as to allow of its being buried in the outer wrappings.

In transformers designed for Y-connection and grounded neutral, some transformer builders, in order to save expense on high-pressure bushings, have grounded one terminal on the case and insulated only such leads as are to be connected to the line; this prevents operation with  $\Delta$ -connections, but otherwise seems unobjectionable. In similar manner, the use of three-phase transformers with the inter-connecting between the phases made within the case reduces the expense and possibility of trouble with bushings.

Eighty thousand volts is the highest pressure that is now practicable for transmission work, but transformers and insulators must be tested, consequently there is some demand for transformers working up to 200 000 volts. The insulation of the terminals of such transformers is the most formidable part of their design. As yet, I know of no satisfactory solution of the problem except to use oil-filled tubes as terminals. A terminal that has withstood 375 000 volts without any indication of weakness is constructed as follows:

The tube was the shape of two truncated cones, bases together; about 12 inches in diameter at the centre, and four inches at either end; it was built up of thin wooden rings, telescoped a short distance into each other, and held together by the conductor which, for mechanical purposes, was made quite heavy, and which was located in the axis of the cones and supported by washers at either end of the tube; between each section of the tube were collars of insulating material, some three inches larger in diameter than the tube, which served the purpose of greatly increasing the leakage surface. After the sections were drawn tightly together by nuts at each end of the conductor, the whole structure was repeatedly dipped in varnish and dried, thus sealing all joints. The terminal was mounted with the lower end several inches under the oil in the transformer and with its largest diameter on a level with the cover; the lower end of the tube was tightly sealed, making the tube perfectly oil-tight.

#### INTERNAL TERMINALS.

At present we are passing through a period of development in

line construction. Each engineer of a new transmission system of considerable length desires to use as high pressure as possible with a line construction of reasonable cost, but few are sure whether 50, 60, 70, or 80 thousand volts is the safe maximum for their conditions. It is common, therefore, for the manufacturers to be asked to make transformers that can be operated at several voltages on the high-pressure side. The result, whether accomplished with series-multiple connection, changing from  $\Delta$  to Y, or simply by taps, usually requires so many terminals, that it becomes quite impracticable to place all the necessary leads outside of the case, even were it desirable to do so; consequently, accessible terminals inside the case must be provided. Again, at these and lower pressures also, it is usually desirable to provide for limited range of adjustment in the ratio, say by 2% steps, with a total of 10%; such changes are usually too small to be made except by means of taps on the high-pressure windings. Except in transformers of very large capacity, there would be no room safely to insulate so numerous terminals above the surface of the oil; the practice is therefore to locate such terminals just under the oil and make them as accessible as possible, either by the removal of the transformer top, or through an auxiliary cover on the top of the case. It is better that each of these terminals be separately supported by glass or porcelain insulators; for a single support, such as a slab of marble, is almost sure to collect sufficient semi-conducting material to cause trouble sooner or later. Such terminals being, at best, rather inaccessible there is danger that a wrong or imperfect connection will be made when changes are desired. The following method of mounting transformers in the tank greatly simplifies the problem of getting at such terminals, especially when transformers are installed under a crane: instead of supporting the transformer proper on the base of the case as usual, it is hung from a strong cover; the interior terminals are placed in about the usual position, but are supported by the bolts carrying the transformer. To get at these terminals it is then simply necessary to raise the cover with the transformer, until the terminals are on a level with top of case; connections may then be made with convenience and safety and the transformer returned to its position in the tank.

#### LOW-PRESSURE TERMINALS.

Usually these present no special difficulties; when transformers are connected in multiple and deliver 500 amperes or

more, special caution should be taken that all joints are soldered or that terminals are of such construction as to have extremely low contact resistances. Taper plugs and receptacles are perhaps the most reliable form of contact for the purpose.

Current in excess of 500 amperes should never be brought out through separate openings in the case, otherwise there will be local heating around the terminal and needless reactance introduced into the circuit. Currents over 2500 amperes should be brought out by means of intermixed bus-bars for the same reason.

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