The Use of Trays and Troughs for Supporting Control and Power Cables in Electric Installations

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THE general design of electric substations and generating stations requires the use of supports, or guides, for directing control wires and power cables from a starting point to their terminal locations.

Three general methods are used to enclose or support control wires and power cables. They are: first, and most generally used, conduit and ducts (this method will not be discussed); second, trays and troughs; third, cleats or racks. The third method is used more frequently now in marine installations than on land, as the electric control wire or power cables used in such installations are jacketed with woven steel braid and are supported by metal racks, straps, or cleats to walls or the ceiling beams.

The second type, trays and troughs, is the subject of this paper. The physical layout of an electric installation does not often lend itself to the sole use of trays and troughs without the addition of some ducts or conduits for branches to channel control wires or power cables to their particular switchboard or apparatus terminations. A station layout of trays and troughs allows excellent use of the physical space near the ceiling or along the walls to trunk large numbers of wires or cables from their respective source, be it in switchgear or at switchboard, to their terminal points. If the proposed project is small, it is entirely possible to plan a complete station installation using only trays or troughs; however, if the station project is large, machine or transformer foundations may block or may be a partial obstacle to space necessary for installing a complete array of trays or troughs.

Outdoor electric apparatus may be supplied with energy by wires or cables laid in weatherproof ventilated raceways mounted on steel columns out of doors, or these wires or cables may be laid in trenches which are reasonably weathertight. The bottom of such a trench is built with a slope so that water falling therein will flow into a sump which is kept dry by an automatic start motor-driven pump.

General

The boundary conditions of a design of a tray or trough system for a modern station are as follows: first, trays and troughs are manufactured or assembled of various materials which should be fire-resisting; second, they may be built as open or enclosed types; third, they may be designed for indoor or for outdoor use; fourth, they may be ventilated or non-ventilated.

Indoor trays or troughs may be designed to be completely enclosed, forming raceways which may be ventilated or non-ventilated; they may be installed in a horizontal position, they may be inclined at various angles, or they may be installed in the vertical position. It is not possible to standardize one particular design for all large electric installations in a given location; therefore each individual station layout provides its particular boundary conditions, which are often a challenge to the station design engineer. The result is that each system must be designed on its own merits, which may require a tray and trough application which is often dissimilar in design to that installed at other existing large stations.

The materials used for trays and troughs are usually steel, although transite is used. Transite is an inert material, which may be awkward to fabricate, but has the advantage of being fire-resisting. However, transite troughs are a manufactured product and special fittings are available for mounting and supporting the complete trough assembly in the field. This material has the disadvantage of being brittle, and careless workmen may break off flanges or crack some of the troughs during the construction period.

Steel tray or trough assemblies may be built using standard steel shapes, such as standard channels or ship channels; they also may be built with sheet steel which is bent to form channels; also sheets of expanded metal are pressed in a die to form troughs, and the rough edges are protected by covering them with a light sheet metal strip.

One of the earliest installations of troughs for the Pacific Gas and Electric Company was in 1925 at Station B, San Jose, see Figure 1. These cable troughs are made of structural steel channels which support 12-kv single-conductor paper-insulated lead-covered cables from low-voltage terminals of a 30,000-kva 110/12-kv step-down transformer bank to the 12-kv bus structure. Similar structural steel troughs support 12-kv cables supplying energy to a 15,000-kva synchronous condensor. Figure 1 indicates that there are two 12-kv cables per phase for the transformer bank cable installation; also, care was taken to enclose the entire group of 3-phase cables with steel supports, therefore no excessive heating occurred in the steel channels. Figures 2 and 3 show other installations using standard steel channels for cable supports at Avon Steam Plant.

Sheet metal trays and troughs are much lighter in weight than structural steel shapes and are easier to mount, support, and install. Figure 4 shows sheet metal troughs supporting control wires at Moraga Substation. These troughs combine lightness of material with ease of installation; also, each trough is a fireproof barrier to wires laid in other troughs.

Ventilated troughs are often necessary when supporting power cables which are carrying heavy currents. Such conductors are a source of heat, especially when the station is operating near its maximum output, resulting in an air temperature in the troughs installed near the ceiling which may increase the temperature of air far above its rated ambient value, requiring a reduction of conductor-carrying capacity. It is not always possible or convenient to install fans or air ducts in or around existing enclosed trough installations to provide cooling air; therefore ventilated troughs allow cables supported therein to operate at a lower conductor temperature because the cables are cooled. Figure 5 shows installation troughs made up of expanded metal carrying three single-conductor 4-kv cables from one 4-kv bus to the other 4-kv bus of a double bus installation in Station G, San Francisco. This type of trough material combines lightness of

Paper 52-282, recommended by the AIEE Insulated Conductors Committee and approved by the AIEE Committee on Technical Operations for presentation at the AIEE Fall General Meeting, New Orleans, La., October 13–17, 1952. Manuscript submitted August 25, 1952; made available for printing September 15, 1952.

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The photographs for this paper were taken by Einar Nilsson of the Pacific Gas and Electric Company, and credit is given to him for his careful work.

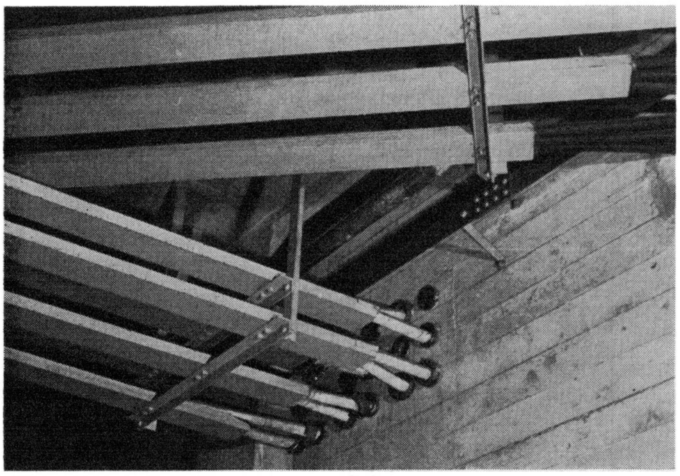

Figure 1. 12-kv single-conductor paper-insulated lead-covered cables (Niagrited) laid on structural steel channels used as troughs, Station B, San Jose

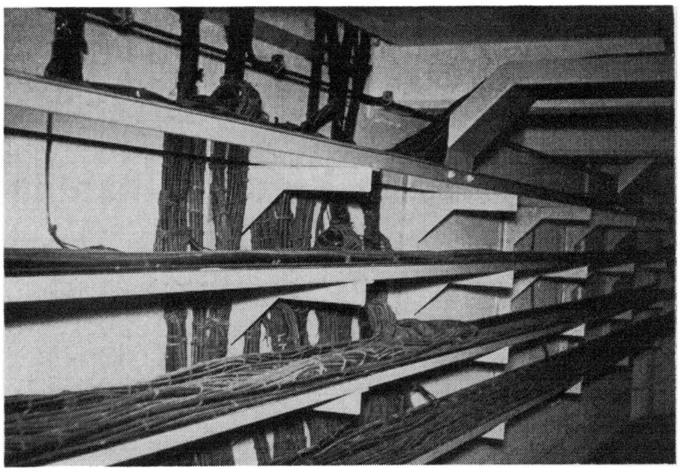

Figure 4. Sheet steel troughs mounted on wall, Moraga Substation, East Bay Division

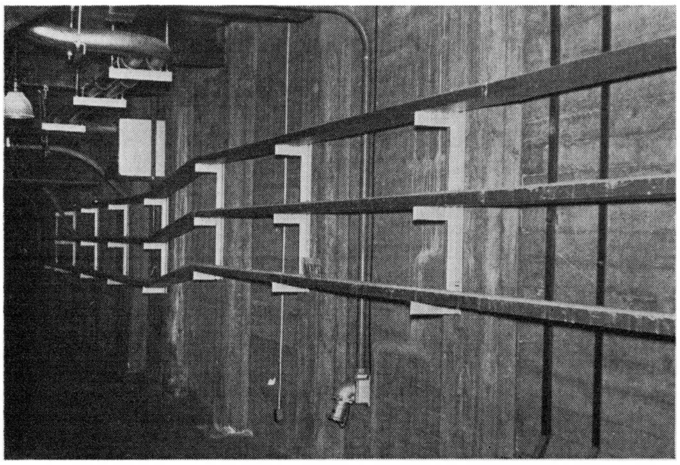

Figure 2. Cables laid in structural steel channels, supported by building columns, Avon Steam Plant, East Bay Division

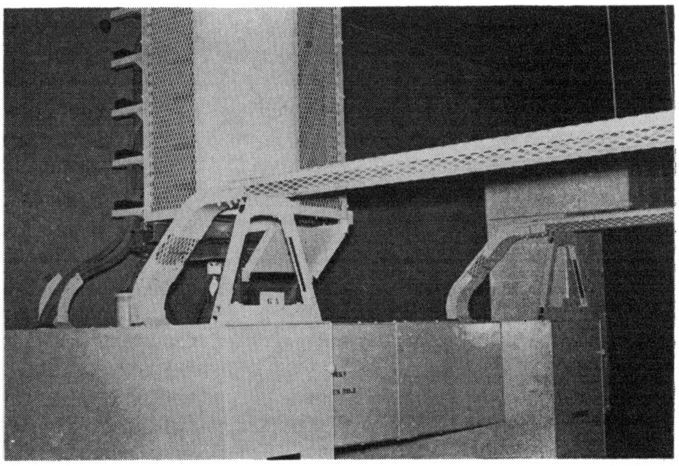

Figure 5. Expanded metal crossover trough supporting cables between 4-kv busses 1 and 2, Station G, San Francisco

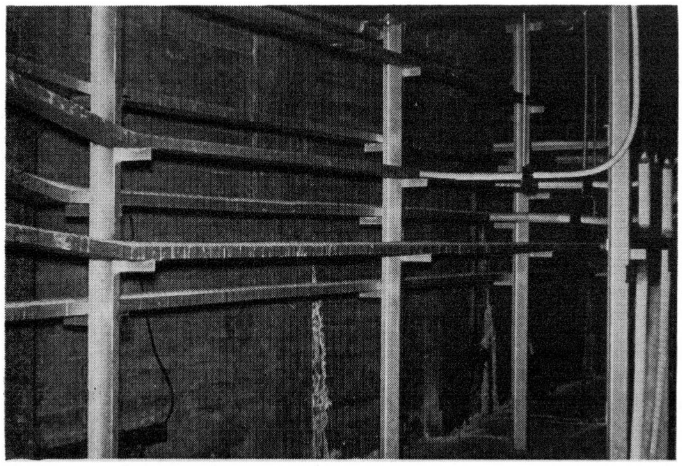

Figure 3. Structural steel channels supported by steel channels form trough assembly, Avon Steam Plant, East Bay Division

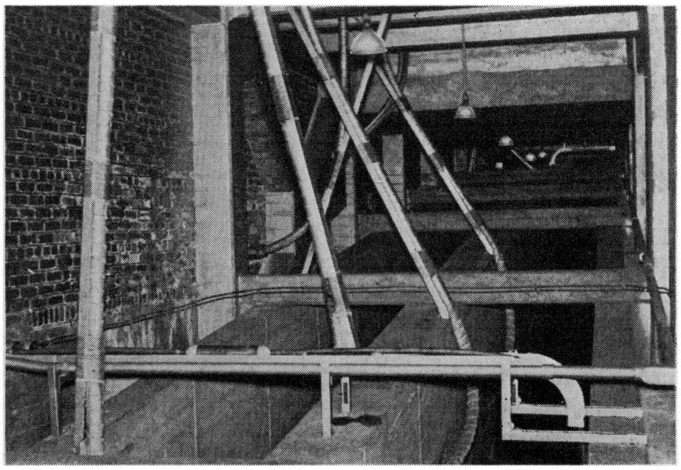

Figure 6. Structural steel channel used as vertical troughs in cable subway, Station A, San Francisco

material with ventilating ability. Such a trough does not collect much dust or dirt; it allows a visible inspection of the cable jackets supported thereon at all times.

The design of cable subways for some stations requires that a portion of the subway must be depressed to clear obstructing roadways or entrances so that the ducts may reach their terminating manholes in the street. In such cases, a deep subway is necessary, resulting in an excessive distance between the ducts in the subway and the floor above. It is not good practice to allow the heavy cables to hang free from the floor above to such a

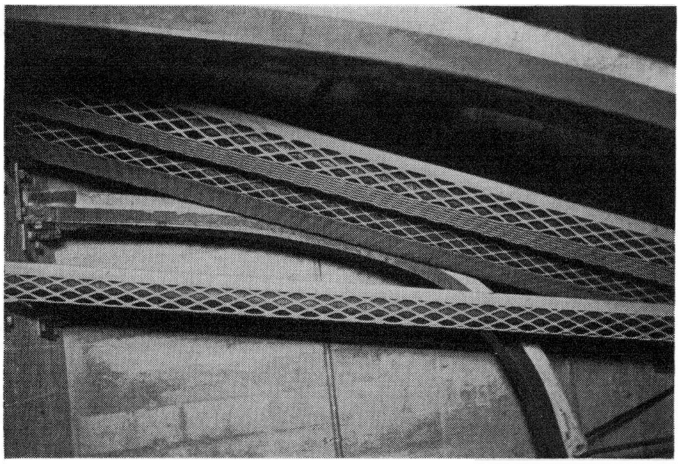

Figure 7. Expanded metal crossover troughs in Station C, Oakland

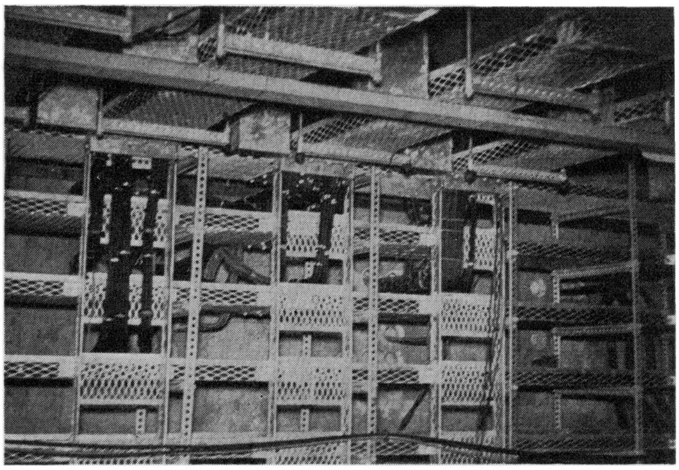

Figure 9. The arrangement of expanded metal troughs under 230-kv control room, Contra Costa Steam Plant, East Bay Division

duct line; therefore it has been found necessary to use vertical troughs for supporting cables.

Figure 6 shows a portion of the 12-kv cable subway at Station A, San Francisco, installed during 1929. Station A is one of our older steam-electric generating stations serving distribution load in San Francisco, therefore many 3-conductor paper-insulated lead-covered cables supplying power to distribution substations radiate from the steam plant. Structural steel channel shapes are used to act as vertical guides or troughs; the 3-conductor paper-insulated lead-covered cable are lashed to their individual vertical channels at short intervals with marline to hold the weight of the cable. During the last few years expanded metal troughs have been installed to carry 3-conductor cables across the subway at Station C, Oakland. Refer to Figure 7.

Some electric installations are so extensive that many control wires are required. The necessary sheet metal troughs or trays may occupy so much space in a basement or area under the control room that the trough installation would be poorly lighted, which may result in areas having dark corners and wall surfaces. Expanded metal troughs offer a solution to such a room lighting problem.

Figures 8 and 9 show the installation of expanded metal troughs in the basement of the control house for the 230-kv switchyard installation at Contra Costa Steam Plant. The installation of troughs was not completed at the time the photographs were taken; also relatively few wires or cables had been pulled in or laid in these troughs. This installation of expanded metal troughs allows standard overhead lighting fixtures to be installed; special fixtures were not required, resulting in good basement lighting. Another example of an open trough installation is shown as Figure 10 at Mission Substation, San Francisco. The examples given so far have been confined to the open troughs, either the horizontal or vertical design.

Trays or troughs may be the open type or the enclosed type. Some installations require control wires to traverse an area where men may be working from time to time or where the control wire route passes oil-filled equipment, such as transformers or circuit breakers, which are a fire hazard. Such a trough installation often is completely enclosed in metal or other nonflammable material.

Figure 11 shows enclosed sheet metal vertical troughs installed at Moraga Substation to completely enclose and isolate one group of control wires from another.

Figures 12, 13, and 14 show the totally enclosed troughs located indoors. Figures 13 and 14 were taken in the basement of a control house at Station C, Oakland, one of the older steam-electric generating stations in our East Bay Division. Such trough installations are considerably more expensive than the open trough and are not justified unless unusual conditions in working areas or excessive fire risks justify this more expensive installation.

Troughs may be designed for outdoor

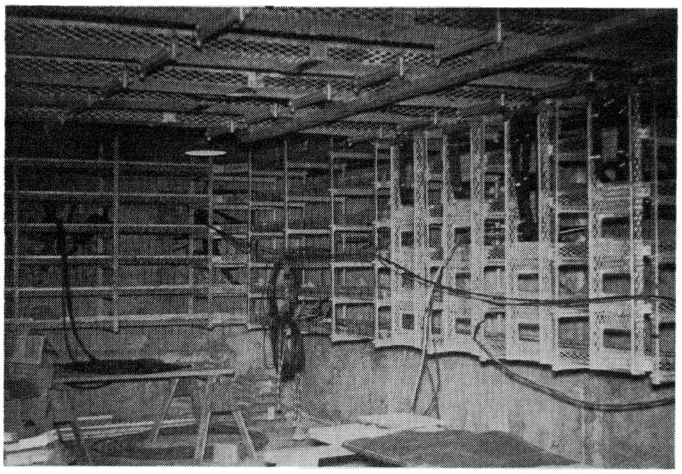

Figure 8 (left). Expanded metal troughs in subway under 230-kv control room, Contra Costa Steam Plant, East Bay Division

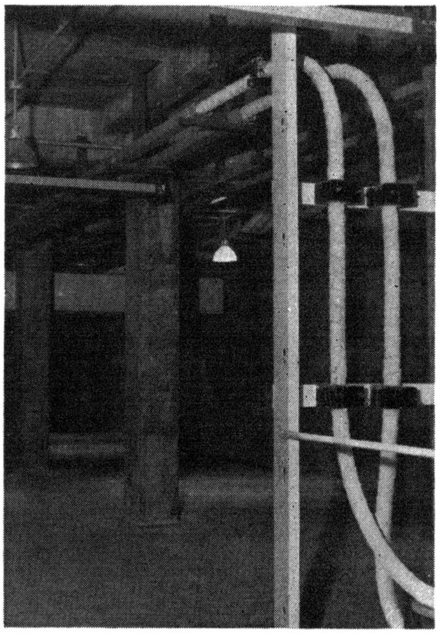

Figure 10 (right). Sheet steel troughs used for supporting 3-conductor cables (paper - insulated lead - covered) at Mission Substation, San Francisco

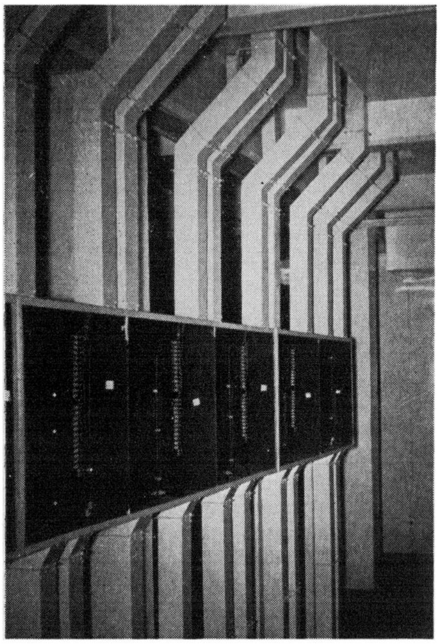

Figure 11. Enclosed vertical troughs at Moraga Substation, East Bay Division

service as well as indoor service. In such cases the metal enclosed troughs are weathertight or watertight. The watertight requirements follow the American Standards Association standard which refers to the tightness of an outdoor metal enclosure when a stream of water from the nozzle of a 1-inch hose under a head of 35 feet is impinged on the enclosure from a distance of 10 feet for 5 minutes.

Such a trough design is used to enclose 12-kv lead-jacketed cables running from the main bus to the transfer bus in an outdoor 12-kv bus switchgear installation at one of our distribution substations. Outdoor ventilated troughs or raceways also are installed to enclose the copper bars connecting rectifier transformers which are out of doors to 12-phase mercury-arc rectifiers installed indoors at the Bay Bridge railway substations. Another example is the outdoor trough as shown in Figure 15; this expanded metal trough supports three single-conductor paper-insulated lead-covered 15-kv cables at the top of a 12-kv outdoor step regulator by-pass switch installation.

Supports

The supports for trays and troughs may be structural steel building columns, building walls, or ceiling beams; however, it is usually necessary to provide additional supports. These may be of three general classes: the first, standard structural steel shapes, such as angles, channels, T bars, or Z bars. These steel shapes are cut, drilled, and fitted for length and size. Often they are fabricated and erected at the point of installation, although this method is not economical for large construction projects.

If the electric installation is small or a number of relatively small installations are being carried on in a nearby given area, the use of lightweight structural steel shapes has the advantage of keeping skilled workmen busy during periods when the general construction work has slowed down waiting for additional shipments of material or equipment. This method of supporting troughs must be scrutinized carefully for each job for total cost and time schedule involved. The design engineer should review the cost of such design before marking drawings showing details of tray and trough design, "fabricate and erect in field."

The second method requires the purchase of special fabricated pressed steel shapes provided with slots, holes, keys, and special fittings for quickly connecting together braces, beams, columns, and

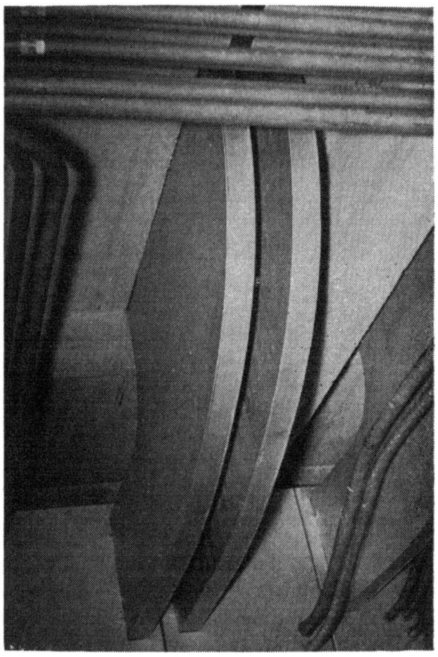

Figure 13. Enclosed metal troughs under control room, Station C, Oakland

supports in innumerable combinations which may form a vertical or horizontal lattice arrangement of columns, braces, and beams. Refer to Figures 5, 8, and 9. The manufacturers of these steel shapes have provided strength tables for many of their column and beam combinations. Our company has used these manufactured steel shape designs in many locations and finds them to be most advantageous for a quick assembly of supporting columns and beams for our design of trays and troughs. The purchase price of the special steel shapes and miscellaneous material is usually higher than the purchase of standard lightweight structural steel shapes mentioned in the preceding paragraph, but the labor of fabricating, fitting, and installing them is materially less

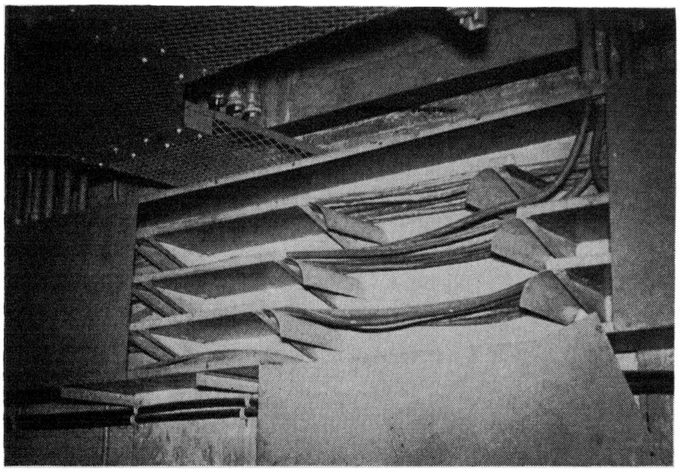

Figure 12. Enclosed metal troughs in basement (one cover removed to show control wires), Station C, Oakland

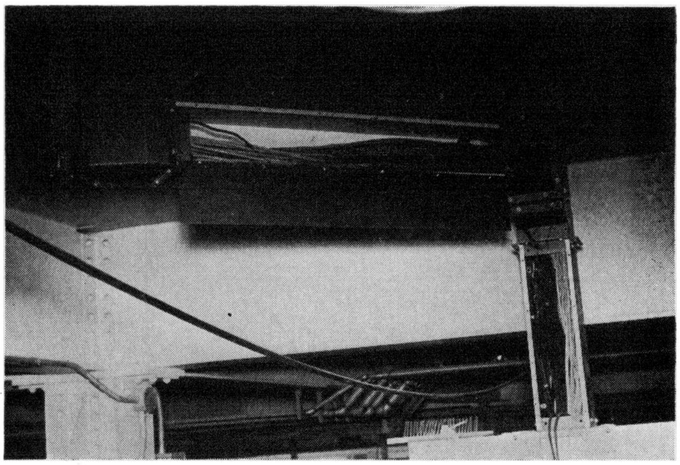

Figure 14. Enclosed sheet steel troughs with covers removed, Station C, Oakland

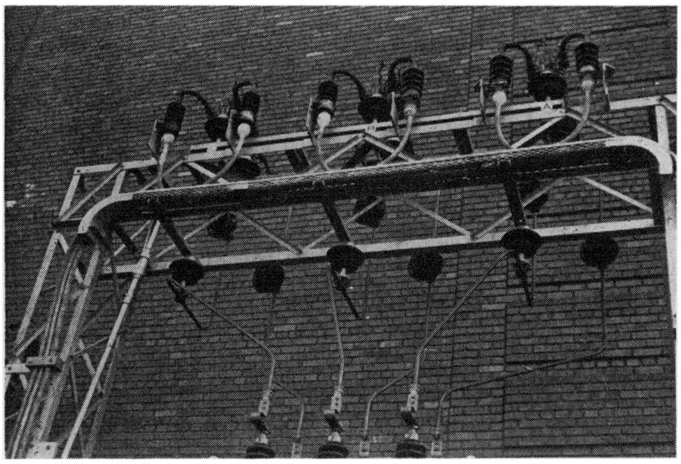

Figure 15. Expanded metal trough installed out of doors, supporting single-conductor paper-insulated lead-covered cables, Station A, San Francisco

and since the labor cost of such an installation is a large proportion of the total erected cost, we have found that the overall cost is less than a custom-built assembly made of structural steel shapes. These special steel shapes have the added advantage of quick erection time, but they allow the trays or troughs to be rerouted readily around obstructions occurring in the field and not shown in the project layout drawings. Another important advantage is that changes can be made in the field with a minimum waste of material and cost to the project, while changes in the field are frowned on by the station layout engineers. It is often necessary at some time or other to make such changes and it is then that the special fabricated steel shapes prove their worth.

The third method for supporting trays and troughs is the use of galvanized iron pipe, bolted together with standard clamp-type pipe fittings. Combinations of columns, braces, and beams can be made up in the same manner as the special structural steel shapes just mentioned. This method is a very useful one for small projects located in the country. Galvanized iron pipe is always available at any country general store, and the workmen require only a pipe vice, hack saw, pliers, and wrenches to cut and erect such a framework in place. The pipe design provides ample strength for control wire supporting troughs, but is usually too bulky for general use in large stations.

Wire and Cable

No résumé of the design of trays and troughs would be complete without a brief discussion of the types of control wire or power cable to be laid or pulled in such trays or troughs. Our standard 600-volt wire and cables used for control purposes and auxiliary power supply are single-conductor cables. The only multiconductor cables used are 5- and 15-kv paper-insulated lead-jacketed types. Our company abandoned the use of multiconductor control cables about 12 years ago for a number of reasons, some of which are as follows:

1. There is a higher first cost for a multiconductor cable than for the same number of single-conductor wires.

2. The number of multiconductor control cables required could not be controlled effectively. Some control cables designed for use in high-voltage switchyards had various sizes of conductors such as number 10, number 8, or number 6 combined in the same cable. We originally standardized on a few multiconductor cables but as the years went on additional cables were added until it became necessary to stock too many control cable combinations.

3. The warehousing problem on a large system such as ours is a real one. We had to carry an excessive inventory of control cables in stock, not only at our centrals warehouse but also at substores at various cities in our area.

4. Our construction people often found that the construction job was delayed and valuable completion time lost due to the inability of maintaining a sufficient stock of all the control cable conductor sizes and combinations that were specified for such jobs; therefore, substitutions were made which were often costly.

5. Color coded control cable was a standard with us at one time, but when automatic transfer and semiautomatic equipment came into common use there were not enough color combinations available to maintain satisfactorily a color code system; therefore, workmen often connected individual wires of different colors together in order to complete a circuit, which caused confusion to our maintenance men.

6. Layout designs using conduits or ducts for multiconductor control cables required a larger size and longer radius bends than those required for the same number of single-conductor cables. It often was found necessary to pull in the next larger size of control cable in order to have a spare conductor (referring to the number of control wires in the cable); however, if the existing conduit or duct were too small, a new conduit had to be installed in an already crowded conduit installation, which was expensive.

7. Our control wires and auxiliary power cables are insulated with an ozone-resistant insulation material (oil base compound) covered with a jacket. Two jacket materials are standard with us: impregnated cotton braid for 600-volt installations and impregnated asbestos braid for 5-, 15-, and 24-kv cables, and the other standard jacket is the heavy-duty nonconducting neoprene, which is used as a covering for 600-volt, 5-kv, and 15-kv cables. All cables insulated with rubberlike materials are the single-conductor type; we have had an excellent service record with such control cables and auxiliary power cables. We attempt to design our trays and troughs so that the cables will be laid therein instead of pulled in; however, in many cases it is impossible to do this. Since our control cables are single conductor, it is convenient to place them in the troughs; the troughs may contain many wires but the topmost wires are not allowed to project above the top of the tray or trough.

Summary

The use of trays and troughs has certain advantages over the installation of a conduit or duct system.

Advantages

1. The control wires are readily available for inspection during the entire run. It is sometimes a little difficult to trace a particular single-conductor wire along the trough that has many control wires laid therein, but we have not found this to be too much of a problem.

2. Individual wires may be added with little or no disturbance to other wires or cables laid in the trough.

3. Auxiliary power cable conductor temperatures are less than the conductor temperature of such cables pulled in metal-enclosed conduits where the dead air space in the conduits or ducts retards the release of heat from the conductor to the room area.

4. The plant layout designer can plan his tray or trough routes with finality since they are usually large and bulky, requiring considerable room area space; a route is planned carefully with all project engineers participating. When the route is approved, a definite building area is allocated to it which will prevent encroachment thereon from other users of building space, such as steam piping, water piping, gas piping, compressed air control piping, and miscellaneous equipment.

5. The cost of material for a trough system is usually less than that required for a conduit system enclosing the same number of wires.

6. When certain control wires are used for the control of particularly important equipment, it may be necessary to enclose the troughs to prevent tampering by malicious individuals; also such enclosed troughs will prevent the spreading of a control wire insulation fire to wires in other troughs.

DISADVANTAGES

1. Control wires in trays or troughs, unless armored, are subject to sabotage, as all control wires are readily accessible. The insulation and jackets of the wires may be slashed with a sharp instrument by passers-by unless the supporting troughs are isolated by height or are enclosed.

2. Control wires having a flammable insulation and jackets are a real fire hazard when laid or pulled in a large trough system; the heat from a fire resulting from a short circuit betwen a pair of wires may destroy many valuable control wires or melt certain insulation material into one mass, resulting in costly replacements.

3. Control wires in an open trough system containing many control wires traversing an area where high-pressure, high-temperature steam or water pipes are installed are subjected to a hazard as they may be damaged by high temperature if leaks spray superheated steam or hot water on the wires.

4. The tray or trough system used in large installations will not provide a support to all control wires or auxiliary power cables to all parts of the plant, but must be supplemented by a conduit or duct system.

Conclusions

The use of the tray and trough system in large modern stations is a design which promises to reduce the initial installation cost of a large electric installation. The tray or trough system does not give as complete over-all safety and security from sabotage as does the conduit and duct system, unless an especial effort is made to isolate them completely by height or by installing a totally enclosed type; however, it has such advantages that the station layout designer can justify the design.

Reference

1. RACEWAYS HELP HOLD DOWN PLANT COST, J. P. Kesler. *Electric Light and Power* (Chicago, Ill.), December 1950, pages 66–69.

Discussion

Victor Siegfried (United States Steel Company, Worcester, Mass.): This paper is very interesting and gives a good description of this method of supporting control and power cables by various types of troughs. One feature visible in some of the illustrations deserves additional emphasis, namely the protection of edges of the trough to avoid cable chafing. Fairing of the ends, or protection of edges by rounding, or possibly by insertion of edges into split fiber rounds, offer means to this end. Some relative movement between cable and trough is possible even with control cables where temperature rises occur, and it should not be overlooked. As pointed out in the paper, inspection is encouraged by open troughs, which may minimize this problem, but care in avoiding possible damage is desirable in the installation phase.

In connection with power cables, the question is raised as to the relative vulnerability of exposed cables to involvement of adjacent phases or circuits in event of faults, as compared with those in enclosed conduits. The writer recalls a major shutdown in the early 1930's at Station A in San Francisco, in which considerable involvement of successive circuits was reported. Possibly more recent experience is available to compare trough systems with conduit in power cable use.

Closure: Sharp metal edges are rounded by fitting lengths of 3/4-inch conduit with longitudinal slits over sheet metal edges as shown in Figure 4 of the paper, or by welding them to structural shapes used as edgings for holes through which cables and wires pass.

In plants where wiring troughs are used, all control wires and auxiliary cables are furnished with jackets of compound that will not support combustion. In general, an external fire will not involve the control circuits and auxiliary power circuits related to more than one primary unit before it is brought under control with the normal fire protection equipment. In areas where control circuits, and so forth, converge, such as the space under a central control room, special precautions are taken. In plants where this space is a room containing no other equipment, storage of combustible materials is prohibited and all building materials are fire resistant. Where it is found necessary to install other equipment in such space, automatic fire protection is provided. Other methods, such as the use of solid metal troughs, transite-lined metal troughs, and transite troughs have been considered but have not been used. Solid troughs of all types are dust collectors and detrimental to ventilation. Solid transite troughs are structurally weak compared with metal troughs. Dust in coal burning plants might justify trough covers.

A major fire will damage control and auxiliary power circuits whether they are in expanded metal troughs, in solid sheet metal or transite troughs, or in conduits. Failure of cables operating at voltages below 600 volts seldom involve other cables if adequate circuit protection is provided. The cables operating at voltages in excess of 600 volts are spaced as far as possible from lower voltage circuits.

LATE DISCUSSIONS

The following discussion and closure were received too late to be included with the papers and discussions.

Effect of a Modern Amplidyne Voltage Regulator on Underexcited Operation of Large Turbine Generators

Author's closure of paper 52-164 by W. G. Heffron and R. A. Phillips, published in Power Apparatus and Systems, August 1952, pages 692–97.

W. G. Heffron, R. A. Phillips: The authors wish to thank the discussors for their contributions to and interest in this paper.

Mr. Concordia's comments were well taken. However, although "practically any well-designed voltage regulator" often will satisfy the requirements, the additional benefits of lower maintenance and improvement of steady-state stability offered by the amplidyne-type regulators make this regulator worthy of serious consideration for all possible applications.

In regard to the effect of such an excitation system on the transient stability limit, as questioned by Mr. Dovjikov, S. B. Crary in Figures 7.6 and 7.8[1] offers some pertinent data. He shows that the use of a constant voltage behind transient reactance during the "transient" period predicates an exciter response of about 0.5 for the extreme case of zero fault clearing time to offset the natural decay of the field flux linkages. He also shows that for reasonable fault clearing times a benefit of only 5 per cent is to be realized even with an exciter response of 2.5, and concludes that such methods as fast relaying and circuit-breaker operation, line compensation, and use of parallel transmission lines with intermediate switching stations offer more benefits than do faster excitation systems. It might be well to remark, as did Mr. Concordia, that these regulators were designed to regulate voltage and that, if improvement in stability had been the primary purpose, a greater stable region may have occurred. Such remarks may be extended somewhat to transient stability improvement still with these qualifications. Since for the preceding reasons little improvement in transient stability can be expected from such an excitation system, this case was not considered.

A decrease in the short-circuit ratio of a generator would cause an increase in its