Open access • Journal Article • DOI:10.1109/T-AIEE.1903.4764316

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Published on: 01 Jan 1903 - Transactions of The American Institute of Electrical Engineers (IEEE)

A paper read at the 176th Meeting of the American Institute of Electrical Engineers, New York, April 24, 1903.

SAFETY DEVICES IN CENTRAL STATIONS AND SUB-STATIONS.

BY PHILIP TORCHIO.

A review of general principles followed in the design and arrangement of electrical apparatus of generating stations, transmission lines and sub-stations and a list of safeguards against breakdowns and devices for localizing and clearing faulty elements of the system. Advantages of storage and reserve supply to ensure continuity of service to customers.

The importance attached by central station managers and consumers to the reliability of service has been brought to bear so strongly upon the designing engineers and manufacturers of high-tension apparatus that the problem of safety has received, and is still receiving, even in its details, the study of every engineer identified with high-tension central station work. This applies not only to the designing but also to the installing and operating of central station apparatus.

What has been achieved is therefore the work of many men, of many experiments, often failures and costly trials and worries; and even now it cannot be said that the problem has found its final and general solution. Therefore I shall approach the subject along broad lines, so as to invite discussion and suggestions on the characteristic features aiming to increase the factor of safety or to insure continuity of service.

High-tension transmission systems may be overhead or underground, or composite overhead and underground. For moderately high voltages, up to 15,000 volts, the transmitted current can be generated directly or can be obtained from step-up transformers. For higher voltages, step-up current only has been used up to the present time. All these different conditions create special requirements for each individual system. In this brief review no attempt has been made to enter into special details particular to any individual case. What follows applies more or less generally to all systems.

Mechanical Reliability.—In this connection no attempt has been made to deal with the feature of mechanical reliability of the generating systems, though it is as important for the mechanical equipment to be safe and reliable as it is for the electrical equipment to be so. In fact the general principle of subdivision and independence of different generating units may be considered to find its application throughout,—from coal supply at the boilers, through the mechanical and electrical equipment at station and transmitting lines, to the receiving substations.

Electrical Reliability.—Proceeding from the generating station to the transmission line and receiving substations, we find the following characteristic features more or less generally adopted or considered desirable from the aspect of reliability of service, Some of the safeguards given in the list appear perhaps as unnecessary and expensive refinements, and probably they would be so for a large number of cases where continuity of service may not be considered absolutely essential. In a large situation, for instance, the lighting and power of a large city, the conditions are different; and if for these conditions safety cannot be obtained in any other manner, these refinements become of paramount importance.

GENERATING STATION.

1. Installation of storage battery on field-exciter bus, at generating station.
2. Equipment of reverse-current relays and circuit-breakers on exciter generators.
3. Equipment of overload relays with time limit and circuit-breakers, on motors of motor-generator exciter sets.
4. Separation and mechanical protection of generator leads of different generators. Also proper insulation and protection against capacity discharges of cable leads.
5. Connection of each generator to bus-bars by means of two oil switches in series, preferably arranged to close independently and open at the same instant.
6. Sub-division of bus-bars, in different sections, enabling operation of generators in different groups. Also selector switches on each generator, enabling the same to be operated on at least two sections of bus-bars.

7. Tie-connections between different sections of bus-bars, enabling us to make, if desired, combinations of different sections or even one common bus-bar.
8. Overload and reverse-current relays on generator switches, these being connected to signal lamps until they have proved their reliability for actual tripping of main switches.
9. Selector switches on feeders providing means of connecting each feeder to at least two sections of bus-bars.
10. Duplication of oil switches on each feeder circuit, preferably arranged to close independently and open at same time.
11. Overload relays on each feeder, with a variable time limit, in inverse proportion to the amount of current.
12. Separation of all wiring and busses inside the station by means of ducts, fireproof septums and grooves in walls, and proper protection against capacity discharges, by the use of good glass or porcelain insulators.
13. In connection with very high voltage step-up transformers, provide low-tension synchronizing busses for generators and switches on the l.t. side of step-up transformers, thereby avoiding synchronizing on the h.t. side of transformers, or closing of h.t. switches on dead transformers.
14. Avoid installation of single pole main switches for each phase of the circuit, and also synchronizing with one pole switch closed and synchronizing transformer across the gap of the other pole switch.

TRANSMISSION LINE.

15. Duplication of transmitting lines to important centers of distribution, selecting if possible different subway routes, or independent transmission lines.
16. Mounting of suitable end boxes on ends of cables at all terminals. Also possible equipment of spark arresters on each end of underground cables.
17. Protection of underground cables in ducts by the use of good fire-proof material.
18. Protection of cables in manholes, using preferably separate manholes for high-tension cables, with asbestos or iron covers on each cable, etc.
19. Protection of lead sheath of cables against electrolysis, either by laying cables in vitrified ducts and rubber cushioned racks in manholes, thereby making the cable insulated from ground along its route, or laying heavy bare copper

wires along the route of cables and connecting solidly to their lead covers in each manhole, these wires providing a secure metallic path for the current, which leaves the cable sheaths to return to the grounded bus at the railway station via the wires suitably connected to the railway return feeders.

20. Protection of transmitting and receiving stations operating overhead transmitting lines by improved lightning arresters.
21. Grounding of neutral of three-phase transmission lines for very high voltages. (General practice in the California transmission plants.) In the case of very high voltages, this grounding seems a necessity.
22. Possibly grounding of neutral for lower voltages and underground cables. (This is done in several places, as for instance, in Chicago, on the 2200 volt 3-phase, 4-wire, 60 cycle system, as well as on the 9000 volt, 3-phase, 25 cycle star-connected system). From the point of view of reducing strains on insulation, this grounding of neutral seems unnecessary for moderate voltages, though it could be made use of for locating accidental grounds on the system, and in indicating and eventually disconnecting the affected feeder, which would be troublesome to locate on a system without grounded neutral and operating several feeders from same bus-bars.
23. Avoid operation of high-tension lines at different frequencies when lines are mounted on same pole line. This to avoid doubling of strain on insulators when two wires of different lines become crossed.

SUBSTATIONS.

24. Separate lines entering substations should preferably be operated independently, laying out independent h.t. busses and transforming apparatus on each line, the transformed current being delivered either to a common set of bus-bars or to independent sets of bus-bars, if the service will allow of this subdivision. In rotary substations, while the rotaries operate in parallel on the d.c. side, they can be fed from independent h.t, lines not operated in synchronism. This allows feeding each substation from different groups of generators at the generating station, or even from different generating stations. In the case of a.c. stations with transformers

feeding into a common secondary set of bus-bars, the primary lines must necessarily be operated in parallel, and therefore from same bus-bars at the generating station. This prevents us from attaining the advantages of duplicate lines and independent sources of supply, as in the case of rotary substations. For this reason, in a.c. systems of secondary distribution, as extensively used in waterpower plants, the adoption of independent groups of generators and independent feeding lines to important centers of distribution is not common. In important cases it may be advantageous to subdivide the customers' supply on different circuits fed from independent lines and transformers operated from different sources of supply. The New York Edison Company operates at present the generators at its Waterside station in two independent groups and whenever a substation has more than one rotary converter in service, the several rotaries are divided among different feeders, fed from different groups of generators at the generating station. The rotary converters being operated in parallel on the d.c. side, the distribution of loads between different feeders and consequently between groups of generators is easily and perfectly accomplished. This distribution is regulated by the system operator at the station, who instructs each substation how to subdivide the loads among the rotaries. The system is laid out to still further subdivide the groups of generators, if the further addition of generators will make it desirable.

25. Receiving lines should be equipped with oil switches and overload relays with variable time limit in inverse proportion to amount of current. When more than one line is feeding a common h.t. bus or independent transforming apparatus operating in parallel on the l.t. side (for instance, rotary converters), each line should also be equipped with reverse-current relays, with variable time limit in inverse proportion to the amount of current, the time limit for these relays being a fraction of the time for the overload relay. Reverse-current relays without time limit are too sensitive to momentary irregularities on h.t. system and cause trouble on this account.

26. Inside the substations all h.t. wiring and construction should be laid out along the same lines mentioned in case of generating station. Also, the low-tension apparatus

and connections should be properly laid out, avoiding crowding and crossing of cables, keeping cables of different polarities separate, and protecting them by means of ducts, septums and pipes as much as possible.

26a. On very high voltage receiving stations, the closing of h.t. switches on transformers subjects them to heavy strains which can, in most cases, be avoided by making alive the transformer from the low-tension side, if the common bus-bars are already fed from another set of transformers. In case of a single set of transformers, it may be advisable to leave the high-tension side of transformer closed all the time, especially in water-power plants.

27. For protection of lines from overloads or short-circuits on transforming apparatus of large capacities, oil-switches with overload relays should be considered preferable to h.t. fuses. The switches should be of proper capacity and should be equipped with locking relays for overloads, exceeding the safe breaking capacity to avoid blowing up the oil-switch. The breaking capacity of an oil-switch will to a great extent depend not only on the character of load, but also on the amount of power back of the short-circuit.

28. Compound-wound rotary converters and eventually also plain shunt-wound rotary converters operated in parallel on a common d.c. bus should be protected by some speed limit device to trip the a.c. and d.c. circuit-breakers on the rotary, when speed exceeds the normal by a certain fixed percentage. The sample here shown is a speed limit device developed by the company with which the writer is connected, in conjunction with a firm which manufactures measuring instruments, adopting their standard mechanism for speed indicators.

29. It is desirable to protect the d.c. side of all rotary converters with circuit-breakers to operate in connection with the speed limit device above mentioned, and also in connection with a reverse-current relay on the d.c. side of the rotary. This reverse-current relay should be equipped with a variable time element in inverse proportion to the amount of reverse current; d.c. overload relays seem to be unnecessary.

30. All relays at different points of the system and their time elements must be properly adjusted, to operate the different circuit-breakers in the proper order, so that if a trouble is once cleared by the opening of certain circuit-breakers, the other relays reset themselves in the normal position, leaving the rest of the system in operation.

31. Emergency connections between different generating stations are considered desirable and have found favor in connecting different water-power plants and also in connecting large generating stations in the same city, as in New York.

32. Of first importance in a lighting situation in a large city is the equipment of storage-batteries at every substation. One large New York company, for instance, has installed or under contract twenty-two 8,000 ampere-hour, 135 volt batteries, and more may be installed in the future.

33. In closing this list of safeguards, it may be added that in all high-tension work, great care should be used in applying tests to the apparatus, especially in making insulation tests on generators, cables, line and transforming apparatus. Breakdown tests can be made on samples, but it is unwise to strain unnecessarily the insulation of the complete plant near the breakdown point. Close inspection of the installation will finally give more satisfactory results than loose inspection and severe tests.

NOTE.—During the reading of his paper, Mr. Torchio referred to a type of lightning arrester tested in Europe and designated as a lightning arrester of the series type. The description of this lightning arrester was presented at the meeting of the Italian Electrotechnical Society on January 20, 1902. The theory of the lightning arrester is not clearly explained by the inventor, although seemingly the apparatus gives good results. It is claimed that the presence of this apparatus on lines equipped with standard lightning arresters causes the latter arresters to cease discharge at any slight atmospheric disturbance as noticed previous to the installation of the series type lightning arrester.

This is an important feature, from the fact that the lightning arrester does not wear out on account of slight static discharges which are always present on transmission lines, and which wear out the apparatus if kept in constant use. By freeing the lightning arresters from this constant wear they would be in better condition to do the work when the emergency arises.