

The lead sheathing of the cable is connected to earth plates at the power house and substations, and at about every half mile along their lengths.

At the power house and substations the cables are brought up above the floor into iron pipes, on the top of which is a brass bell. The lead sheathing is wiped on to the bell, and inside the bell the three cores are separated and jointed up to three separate rubber insulated cables, the joints being carefully insulated and separated, after which the bell is filled with an insulating compound, and fitted with a wooden cap, through which the three leads pass into a disconnecting box, containing three marble compartments, into which the corresponding leads of the two paralleled cables are brought, and from which leads pass to the feeder switches in the power house or to the high-tension bus-bars in the substations.

Each of the cables is distinguished by a number which is engraved on a brass plate fixed to the wooden cap of the brass bell at each end of the cable. The three cores of each cable are also similarly identified at each end. To further minimise the chance of confusion if it should be necessary to disconnect any cable, the wooden caps at each end of the same cable are painted black or white, while for purposes of identification when repairing any cable in the trough, the numbers are so allotted that of the two cables to any substation, that bearing the odd number lies to the left of the trough as one faces in the direction of the substation. The position of the cables and joints were all carefully located, and a set of sixty-link plans is kept, on which the routes are carefully plotted. This set of plans and the system of numbering the cables has proved of the greatest service, in minimising the delay in cases of breakdowns, or safeguarding the lives of those engaged in repairs to the cables.

The cables, when laid and jointed up from end to end, were subjected to a high potential test of 20,000 volts effective alternating for thirty minutes between each core and the lead sheathing to which the other two cores were joined during the tests.

Cables designed for a working pressure of 6,600 volts are usually subjected to a test of 13,000 volts when laid, and for comparison a cross-section of a cable designed for the usual requirements is shown in the drawing side by side with the cross-section of the cables described.

A description of the methods adopted in testing and locating faults can hardly be considered as coming within the scope of this paper, and so, although very interesting and instructive problems have been met with in carrying out the tests, space cannot be devoted to the subject here.

It is well known that the sudden opening or closing of a circuit carrying alternating currents at high potentials may set up surges of potential sufficient in some cases to puncture the insulation of the cables, and so ultimately lead to a breakdown. To prevent this, there are connected across the three cores of each pair of cables at both ends a series of General Electric spark gap lightning

arresters, consisting of a series of gaps between cylinders of special non-arcng metal, in series with a non-inductive graphite resistance. These arresters are adjusted so that should the potential at the ends of the cables rise above about 15,000 volts, a discharge will take place across the gaps, the graphite resistance preventing any great flow of current. There are about fourteen gaps of about one-thirty-second inch across each phase.

The substations are substantially built brick buildings, with red tiled gable roofs, and are divided into rooms for the batteries, and one for the machinery and switchboards. The latter room is generally about sixty feet long by thirty feet wide; with a clear height of eighteen feet to the tie-beams of the roof principals, and is spanned by a travelling hand crane, fitted with blocks capable of lifting six tons.

Except at Newtown and Randwick there are two battery rooms one above the other, of the same general dimension as the converter room, except that the height is about fourteen feet. At Newtown both batteries are placed on the same level in one large room, while at Randwick there is at present only one battery. The floor of the converter rooms and of the lower battery rooms is of concrete, while the floor of the upper battery room is covered with sheet lead. The entrance to each room is through a door ten feet wide, fitted with a roller shutter. The substation at North Sydney differs somewhat from the substations on the city side, the machinery being installed in a room in the Ridge-street power house, formerly occupied by the machinery for working cable trams between Milson's Point and Ridge-street, and by the three 100 kilowatt D.C. generators which supplied the Mosman and other outlying lines in North Sydney. Two of these generators have been moved into another room, and belted to a countershaft driven by one of the two original engines; while the third generator and second engine, with the cable drum and shafting, were removed altogether to make room for the substation machinery. The two generators and steam plant are now shut down, and held in reserve. The apparatus in the converter room in all the substations comprises the following:—

Two six-pole shunt wound 450 kilowatt three-phase rotary converters.

Six 175 kilowatt single-phase air blast transformers.

Two fifty-inch fans, direct coupled to two one-horse-power induction motors.

Two fifty-kilowatt differentially wound boosters, together with the necessary switchboard panels.

The high-tension bus-bars, which are connected in a disconnecting box to the ends of the incoming high-tension underground feeders, are mounted behind the oil switch cells as at Ultimo. In the substations, however, there are only two oil switch cells, the three poles of each of the two switches being contained in one oil vessel instead of being separated in three compartments as at Ultimo. The switches are operated by levers as previously described, and are similarly fitted with overload relays and signals.

The high tension panels and switch cells are placed across the station at one end, at right angles to the main low tension board, which runs parallel with the length of the station, secured to a framework of angle irons. in front of a switchboard pit four feet wide by four feet deep, built against the wall separating the converter and battery rooms. From this pit the cables pass to the machinery, through earthenware pipes, laid about one foot below the floor level.

From each oil switch a three-core rubber insulated cable passes down through an iron cable standard to the earthenware duct beneath the floor and up through a similar standard, or uptake, to the primary bus wires of the corresponding bank of three transformers, which are arranged in delta, and transform from 6,000 to 375 volts.

The delta connection is usually chosen as in the event of damage to one transformer it may be cut out of service, and the other two still be used to supply three-phase current, and to prevent undue overloading of the transformers in such a case, their combined capacity is somewhat in excess of that of the converter to which they are connected.

The transformers and blowers are placed over pits or air chambers, into which the fans deliver the air for cooling at a pressure of about three-eighths ounce. The primary or high tension leads are brought out at the top of the transformers, and connected to the bus-wires previously mentioned, while the secondaries are brought out underneath and connected to three bus-bars in the pit, from which three cables run to the corresponding panels of the low tension board. The induction motors driving the fans are connected to these bus-bars through three-pole switches mounted on the casing of the fan.

The rotary converters, which operate at a speed of 500 revolutions per minute, receive the three-phase alternating current at 375 volts, and convert to 600 volts direct current.

The field yoke is divided horizontally into two halves, so that the upper portion can be lifted off to allow of repairs, and the whole yoke is so mounted that it may be moved on the bed-plate parallel with the shaft and clear of the armature. The shaft is extended beyond the bearing at the A.C. end, and has mounted upon it the rotor of a forty horse-power induction motor, the stator of which is supported on a bracket bolted to the bearing pedestal.

These induction motors, which are wound for 375 volts and 750 revolutions per minute, are intended for use in starting up the converters, and running them up to synchronous speed in case direct current should not be available for starting. They are, however, very seldom used, the converters being normally started as direct current motors off the batteries, and synchronised.

For use in case it should be necessary to start up the converters from the alternating current end, a field-break-up switch is mounted on the frame of the machine, which, when open, divides

the field winding into three portions, so as not to endanger the field winding by the voltage induced in the field by the alternating current in the armature when at a standstill.

For us in discharging or charging there is installed for each battery a differentially wound booster, driven by a six-pole 100 horse-power direct current motor, operating at a speed of 900 revolutions per minute.

With the series field idle, and the shunt field excited off the 600-volt bus-bar, the booster will boost 500 amperes 100 volts; while, when the series field is carrying 1,000 amperes, and the shunt field excited as before, the machine will give 100 volts in the reverse direction, the series field being opposed to the shunt. The armature is connected on the negative side of the battery, while the series field is in the negative end of the converter main circuit, so that when the load on the station exceeds a certain limit the battery discharges; while, if the load on the station is below the limit, the battery is charged, and fluctuations of load on the converters and generating station is reduced to a minimum.

The switchboard, which is of blue Vermont marble, comprises, in addition to the two high-tension transformer panel above-mentioned, the following panels:—

Two alternating current rotary panels, controlling the circuits from the transformers to the converters.

Two direct current rotary panels, controlling the circuits between the converter and the direct current bus-bars.

Two motor panels, controlling the booster motors.

Two generator panels, controlling the booster circuits.

Two battery panels, connecting the battery positive poles to the positive bus-bar.

Four feeder panels, each controlling two of the cables feeding the trolley wire.

With the exception of the feeder panels, which are sixteen inches wide, all the panels are ninety inches by twenty-four inches by two inches.

The field and starting rheostats are placed in the switchboard pit, which is covered by a movable flooring of hardwood. All the main circuits are protected by magnetic blow-out circuit breakers of the well-known type made by the General Electric Company who supplied and erected the machinery, cables, and switchboards.

Each battery consists of 280 cells of the A.F.A., or German Tudor make, having a capacity of 500 ampere hours at the one-hour rate, and capable of supplying 1,000 amperes for brief periods. Only 260 cells are filled and charged, the remaining twenty being held as spares.

The cells are of wood, lined with sheet lead, and there are nine positive and ten negative plates, and the cells hold about fifteen gallons of electrolyte.

The cells are placed each on four porcelain insulators on wooden stands, which are fastened throughout with wooden dowels. There are two rows of cells on each of the stands, which are supported on large glass insulators.

All the wood and ironwork in the battery rooms, with the exception of the battery stands, which are specially treated, is protected with acid-proof paint. Distilled water is used for topping up the electrolyte, and a still, having a capacity of three gallons per hour, is installed in each station; the boiler, which is heated by gas, being placed in the converter room, and the condenser and storage tank in the upper battery room. From the tank a line of piping is led round each battery room, with nickel-plated taps at convenient intervals.

Two telephones are installed in each substation, one being connected direct to a small exchange on the high-tension board at Ultimo, while the other is connected to the nearest tramway exchange.

To avoid confusion, no mention has, so far, been made of the additions and extensions to the power house and substations, either proposed or now in course of completion; and the foregoing description of the plant comprises what is now in regular operation, including a second converter at Randwick, for which a foundation was originally provided, but which was not installed until the beginning of the present year. To bring the matter up to date the additions will now be briefly described.

In the power house the old tubular boilers installed with the original D.C. plant are being replaced with Babcock and Wilcox boilers, with mechanical stokers, and the upper boiler room and coal bunkers extended for the complete length of the station.

A turbo-alternator, of the Parsons' type, of 1,875 kilowatts capacity, has been ordered, and the work of erection will be put in hand almost immediately. The capacity of three of the feeder panels is to be increased by replacing the present instruments, and three new feeder panels and oil switch cells are to be erected. The converter room at Newtown substation has been extended by the addition of thirty-five feet to its length, space being thus provided for three more converters with their transformers and switchboard panels. Two of the new converters have now been erected. In carrying out the extension it has been necessary to alter the position of the high-tension cables, transformers, and high-tension switchboard. The five high-tension oil switch cells and switches, and all high-tension apparatus, have been placed in a basement, the construction of which was made possible by the fall of the ground. The size of the City substation, when built, was restricted to that of a certain piece of land. The converter room was fifty feet long by thirty feet wide, but was made two feet higher than those in the other stations to allow of the transformers being placed on a gallery if necessary. Extra land has, however, since been made available, and a second room built beside the old converter room, having the same dimensions, the dividing wall being pulled down.

The transformers are being placed on a gallery; the high-tension cables have been moved, and foundations provided in the new building for three more converters, of which two have been erected, but are not yet in service.

For the North Sydney substation a new converter arrives this week, and, with its transformers, will be placed on foundations provided when the original converters were installed.

Plans have now been prepared for an addition to Waverley substation, which will provide for two extra converters and transformer banks, of which one has been ordered.

A new substation has been built at Stephens-road, Botany, about one mile from the Botany terminus, for the supply of power to the La Perouse line when converted. The length of the high-tension cables to this substation will be six miles, and a contract for laying them has been let to the Henley Cable Company, who have just completed the cables for the City Electric Light system. These cables will be made to the same specification as those already described, except that there will be two layers of jute over the lead sheathing in place of one. The troughing will be of the single planking, but of the same general design as that previously used, while the filling-in material will be pure Trinidad bitumen. The substation has already been built, and a battery of the same type and size as those already described was charged in May of this year. The converter and battery rooms at Botany each measure thirty-two feet by fifty-two feet six inches, and in the converter room provision is made for the same apparatus as originally installed in the other substations, but the arrangements are slightly different. The high-tension cells will be placed on a gallery (the room being made a little higher to allow the crane to clear the structure), and the high-tension panels beneath the gallery are placed in the same line as the main board, while each bank of transformers is placed between its converter and the side wall. By this arrangement it is possible to extend the substation lengthwise without having to move any of the machinery or apparatus. One converter and one booster have been ordered for this substation, which will be put into operation about October next.

Another distinctive feature of this substation is a cable tower by which the low-tension feeder cables are brought into the building in a neater manner than in the other stations, the feeders passing from the switchboard pit through a tunnel to the base of the tower.

In all the new converters, the induction motor for starting has been abandoned, half voltage taps being provided on the transformers, and provision being made for the insertion of reactances into the alternating current side for starting, while the field-break-up switch on the machine is arranged so that the field may be reversed in case the polarity of the machine should be wrong.

It has not been considered necessary to describe the very complete system of return boosters lately installed in the power house and substations, as they do not necessarily form a part of the alternating current of distribution.

In writing this paper many details have been described which will appear unnecessary to those members who are well versed in electrical engineering; but it has been borne in mind that the majority of the audience will probably belong to other branches of the profession, and I hope the electrical portion will pardon those descriptions which may appear to them unnecessary.

In concluding, I wish to express my thanks to Mr. Brain, the Chief Electrical Engineer, for permitting me to make use of the departmental drawings.

