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A 2750-VOLT DIRECT CURRENT SYSTEM.

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(To be read before the Electrical Section, 9th December, 1909.)

The transmission of energy becomes a remarkably simple matter when direct current is employed, and given that the generators, rotary transformers, and apparatus could be brought to a sufficiently high voltage without the cost becoming prohibitive, and that they could be guaranteed as reasonably reliable and durable, then undoubtedly direct current would be an ideal agent. But the difficulties have proved so many, and the risks of installing such plants so formidable that, except for a few isolated instances, direct current systems of any size operating at over 1,000 volts are practically unknown. Moreover, the results obtained from the few in operation can scarcely be called inviting enough to encourage such enterprise in this field.

Before going into details of the particular system under review, it may be as well to give a brief description of the district which it is operating.

Twickenham is one of the southwestern suburbs of London. It is chiefly residential, as are the other towns along that part of the Thames, and, except for a few sawmills and the like, and the National Physical Laboratory, there are no power-users. This lack of day load is probably what influenced the designers to run D.C. in the first instance, for otherwise it is more than usually well-adapted to alternating current. It is so scattered that there has been constant trouble in keeping the low tension network balanced and up to standard pressure. The area supplied at present is about 25 square miles, but the company have powers which will eventually treble that total.

The low tension mains, comprising about sixty miles of complete three-wire, are all linked up into one network, fed at suitable points by rotary transformers, and, of course, largely from the central. The generating station is situated in about the centre of Twickenham, about two miles from one end of the district now operated, and between six and seven miles from the other. The transmission is by direct current at 2,750 volts, with future intentions of making it three-wire at 5,500 volts.

Generating Station Equipment.—The present H.T. equipment consists of two 200 K.W. 2,750-volt generators and one 100 K.W. 2,500 : 500-volt rotary transformer, with booster attached for raising the low tension side for transforming up, so that whilst during the day one H.T. set is run, supplying the two principal sub-stations and the home rotary transformer, during heavy loads the home rotary transformer is taking current from the L.T. board and transforming up. This has saved installing another generating set.

Generators.—The generators are four pole, direct coupled, running at 475 R.P.M. They are shunt wound, with shunt separately excited at 500 volts. These machines have now been running for about five years, and it is a curious fact that, although they have continually been in trouble from flashing over and other causes, the armatures have never had even a new former. For two years each machine was running without a break for eighteen hours on each alternate day.

Switchboard.—The switchboard (Fig. 1) consists of nine panels. They are of iron throughout, with mica washers and bushings. There are two generator panels, six feeder panels, and a voltmeter panel. The circuit breakers are D.P. air break, and are ranged along the top, with a slate division between each set. Immediately behind are the change-over switches, and above these the busbars. The generator switches are fitted with maximum and minimum cut-outs, the minimum coil being fed from the 500-volt shunt circuits. The feeder cut-outs are simple overload. At the bottom of the generator panels are the field rheostats and field breakers. Five of the feeder panels are fitted with line regulating resistances, L.T. long-range operating switch, and parelleling voltmeters for running the automatic sub-stations. The method and connections are shown on Fig. 3, and will be referred to later. Each feeder is fitted with a surge arrester, consisting of a series of spark gaps in series with an oil tank resistance. These arresters were installed after one of the lines had been twice broken down on charging. Lastly, the voltmeter panel, which, as will be seen from the figure, has two electrostatic meters, and a plugging arrangement for parelleling and for plugging on to the three bars.

Transformers.—The rotary transformers (Fig. 2) are two-pole machines of overtype design, with double wound armatures running

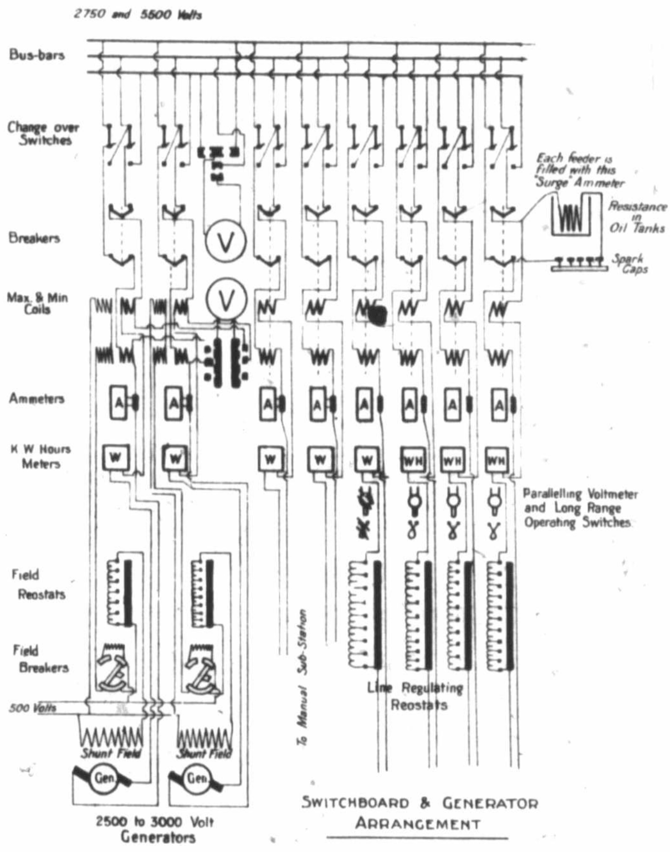

Fig. 1

in a single field, and have copper brushes. They run at 500 R.P.M., and have a fixed ratio of 5 to 1. The regulating is done by the resistance in the high-tension circuit. They are started up as series motors, and for this purpose are fitted with a small series field, which works in conjunction with a short-circuiting switch.

The actuating solenoids of this switch are connected in series with the shunt-field circuit, which in its turn is connected straight across the L.T. end of the transformer. These switches are so adjusted that, when the L.T. pressure equals about 450 volts, the series field is cut out. The transformer bearings have small oil pumps working

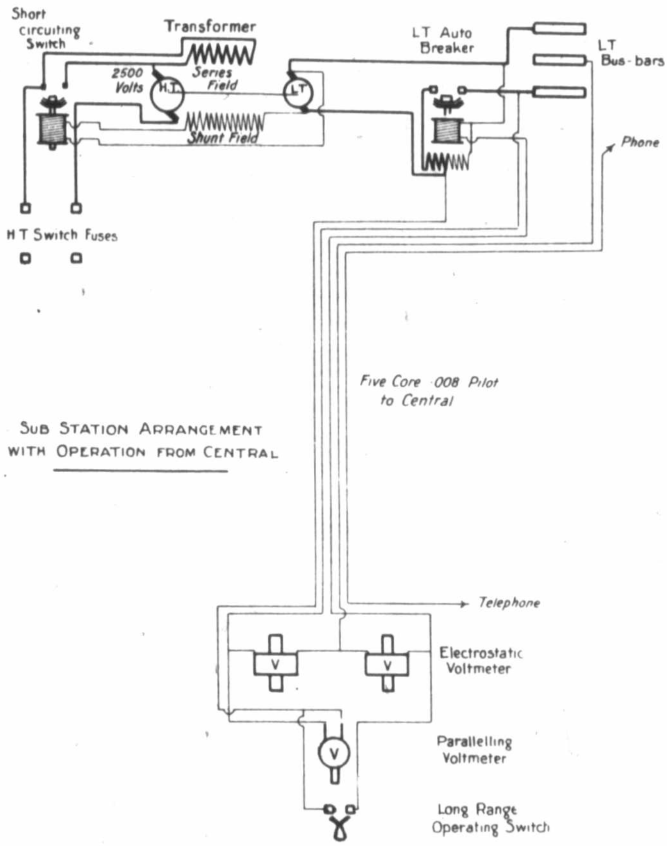

Fig. 2

off a cam on the shaft ends, as well as the usual oil rings. These oil pumps have proved somewhat of an expensive luxury, as will be shown later. The figure is of the home transformer, and shows the method of attaching booster necessary to make up-transforming possible.

Sub-Stations.—There are at present four sub-stations, and these form what is perhaps the most interesting part of the system. One of them, the Teddington, is a manual, equipped with two 100-K.W. transformers, H.T. and L.T. switchboards, and a 1,000 ampere-hour battery. This is arranged after the same pattern as the generating station, but it is the automatic stations which will most likely prove the more interesting. Each of these is equipped with a transformer of 50 or 100 K.W., a set of balancers worked by a time-switch, and a distance operated single pole L.T. circuit-breaker. The only H.T. apparatus is the short-circuiter and a pair of switch fuses for isolating purposes The Molesey station differs in that it has a 600 ampere-hour battery and a small L.T. switchboard, but it is so arranged that it is worked automatically with the battery floating. A man cycles out every morning to put the battery on charge, and again in the afternoon to take it off. The other stations are visited only about two or three times a week.

The regulation of these stations is done from the central by means of the line resistance, and for starting up, etc., a five core .008 armoured pilot cable is run back from each. (Fig. 3, sub-station arrangement.) Coming to the method of connection, it will be seen from Fig. 2 that the actuating solenoid of the L.T. auto is connected from the opposite pole of the transformer and through to the "firing switch" at the central. From the firing switch another line is run back to the transformer side of the auto. Being on this side is important, as, were it on the other side, the switch could be operated whether the machine was running or not. As it is, when the machine is shut down there is no potential across the firing switch. This same line also serves for the paralleling voltmeter, whilst for the other side of this meter another line is taken from the busbar side of the auto. Across these lines the electrostatic pilot voltmeters are connected, the fourth line in the cable serving for their neutral and the fifth for the telephone.

Some Operating Troubles.—Taking the sub-stations first, the most frequent cause of trouble has been the H.T. brushes. These, as has been explained before, are copper, and when the commutator gets rough they have to be literally soaked with oil to prevent them wearing down between visits. Sometimes, too, they slip. Except for burning up the brush-holders, this never does any actual damage, and it is amusing to note that invariably the first intimation of such a state of affairs is received from a policeman, hastily despatched by the alarmed residents in the neighbourhood. So far as actual damage is concerned, the oil pumps and the L.T. autos have been the worst offenders. The weakness in the oil pumps is a sight-glass fitted on the pipe leading into the bearing cap. These glasses occasionally crack, the oil is pumped out on to the floor, and central is probably notified by the breakers coming out through the shaft seizing. Coming to the switches, it is necessary to first give a description of their action. The solenoid plunger operates the switch through a ratchet and pawl arrangement. When thrown in the switch is held by contact friction, the exciting current is broken, and the plunger falls back to its original position. Next time the solenoid is excited the switch is pulled out, and so on alternately. The trouble is the pawl springs. These are only light spirals, and often break. When this happens the switch is only partly thrown in—to be exact, just into the carbon ends. Naturally, in a short time the switch resembles an arc light, and, unless the operator notices the jumpy, or falling load, he is not aware of anything untoward until the policeman arrives or the switch burns out.

Then there are the short-circuiting switches. These are designed to fall out by gravity when the machine is shut down, but occasionally they will stick up, and then the machine cannot be started until someone is sent down to pull it out. Another peculiarity of these switches is sometimes in evidence on starting up. If the pressure is higher than usual, or the starting resistance is cut out too quickly, the inductive effect set up by the series field is so considerable that a surge is started in the shunt, and the short-circuiting switch is thrown violently in and out for twenty, or perhaps thirty, times before the machine begins to revolve.

There are six transformers installed, and whilst being subjected to all manner of strain through short circuits, etc., they have never been known to flash over. This may be due to the copper brushes. The chief trouble found with them is in the armatures and series coils. The latter, unless kept scrupulously free from copper dust, are liable to break down to earth. So far the system is not grounded on one side, and on one occasion the series field of an outlying transformer broke down to earth when the other side of the system was grounded in one of the generator ammeters. The writer's head was about three feet from the ammeter when it went, and the resultant display has founded a lasting impression.

There is one transformer in particular which seems to have an unfortunate penchant for discharging across the field air gap. The armature has been twice burnt out, probably through this, and the last time it was rewound it discharged so badly that it could not be run. There was a continuous stream of sparks right along the armature tunnel. It was found that the only measure to stop it was a coat of insulating paint on the pole-pieces. A standing menace which has been active on one occasion is the danger of losing the shunt-field. This has been provided for in so much that it is made fool-proof by dispensing with lifting attachment on the L.T. brushes. What is likely to happen if the field is faulty was seen on the home transformer on the first starting up of the plant. Somehow a faulty connection in the shunt-field circuit was overlooked, and when the current was switched on the machine built up in speed until the binders burst. An idea of the speed attained may be gathered from the fact that when the current was switched off the armature took well over five minutes to come to rest. Pieces of the debris were found on top of the crane.

A serious drawback to these transformers presents itself in time of mains trouble. The L.T. network pressure is 480 volts, and, in time of a bad short-circuit, this may fall as low as three, or even two hundred, volts. The transformers will not come down as low as this, and to switch them in at, say, 400 volts is simply to throw the breakers out. The only way is to catch them speeding up, but then the series field is not cut out. Once, in very desperate straits through a dead short on a .5 feeder, a transformer was switched in in this manner as a last resource, in the hope that the short-circuiting switch would act on load. But the hope was misplaced. In five minutes the machine was on fire, and the fire brigade was down squirting chemical extinguishers over it.

Coming now to the generators, as has been previously stated, the chief trouble is in commutation. This remark must not be misunderstood, for, when everything else is right, the commutation leaves nothing to be desired. But it is when there is outside trouble that the generators behave badly. A transformer burning out, or a short circuit on the mains, and sometimes even a big jump in the load, will cause them to flash over. Beyond burning off a belt or pitting the commutator no harm is done to the machines. But it is awkward in other ways, for if two machines were running in parallel, and one went, undoubtedly the other would go too. As was remarked earlier, it is the intention in the future to run it as a three-wire system, with two machines in series, and if ever that is tried the results will be very interesting.

The switchboard has not so far given any trouble, except for voltmeter panel blowing out. At first there was a little difficulty in breaking the shunt-field current. The switches are single pole, and threw a high resistance across the shunt when breaking. They are enclosed in an iron frame, and the arc on breaking would sometimes ground the L.T. system. Finally, after an operator's arm had been burnt, they were enclosed in asbestos boxes.

Summing up, the most inefficient part of the system is in the method of regulation. When, as is nearly always the case, one station is taking a comparatively heavy load, then the H.T. pressure must be run 100 or 200 volts higher than would suffice for the other stations. Consequently, this energy has to be absorbed in the regulating rheostats, and entails a very serious loss. Apart from this, the transformer efficiencies are very high.

Finally, a word on the mains. These are, of course, in all cases underground, and, except for the troubles before referred to, due to the surging, there was only one fault developed on the H.T. system in five years. The cables are .5 two-conductor concentric, paper insulated, with lead sheath and outer steel wire armouring. The method of laying is to draw them into earthenware conduits. They cannot be spoken too highly of.

Perhaps, though it is foreign to the paper, a few concluding remarks on the L.T. system of mains will be allowed. The experience with these has been so remarkable that it is felt to be justified, and, as underground mains seem destined to come on the tapis here sooner or later, it may prove of interest.

The L.T. mains are of what is known as the solid system. The cables are coated with vulcanized bitumen, the only other protection being a covering of thick braid. They are laid in wooden troughs, supported on wooden bridges, the troughs then filled solid with bitumen, and a layer of tiles put on top.

These mains have been an endless source of trouble. The troughing rots, the bitumen cracks, and the water gets through to the cables. Sometimes a "short" will burn away as much as fifty feet of cable. But the most remarkable thing is that the mains have been opened up and not a vestige of copper found for as much as 18 feet, yet at the same time a motor has been working beyond the break.

There have been as many as three breakdowns in a day, and for a year the average mains faults have not been less than four a week.