HIGH-VOLTAGE DIRECT-CURRENT SUBSTATION MACHINERY

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The rapidly increasing number of installations of high-voltage direct-current apparatus in railway systems proves the commercial success of that method of operation. As a result, wide-spread interest has been aroused in the design, operation, and characteristics of the equipment. The following article contains very interesting information on the frequency, voltage, current, overload capacity, commutation, influence of short circuits, etc., of the high-voltage direct-current machinery which is being used.—Editor.

The idea that the application of 1200 volts or higher voltage direct current to electric railway work constitutes a system radically different from one employing 600 volts, and that the difficulties attending the operation are greater, has been shown to be entirely erroneous.

The design of higher potential direct-current substation machinery follows a logical advance in the design of 600-volt apparatus, not a single good element being discarded or replaced. The one feature that permitted the use of higher voltages was the successful application of the old idea of commutating poles to motors and generators. This has made possible the use of higher voltages per bar and higher commutator speeds, which result in greater output per pound weight, or, as might be better stated, a reduction in the cost per kilowatt capacity.

In the first 1200-volt and 1500-volt installations two 600- or 750-volt machines were connected in series, the fields of both machines generally being connected on the ground side. The design of these machines was identical in every respect with standard 600-volt machines with the exception of the necessary increase in insulation. Experience indicated that the designs then adopted met every condition of operation with marked success, except it was found in a few cases that trouble was experienced by flashing over on those machines in which the brush rigging was supported from the pillow block. In later designs it has been the practice to support the brush rigging from the magnet frame or in some cases from a special yoke attached to the base.

With the exception of 60-cycle synchronous converters, it has become the usual practice in designing substation apparatus (for operation up to and including 1500 volts) to obtain the desired voltage from one machine. Synchronous converters up to a frequency of 35 cycles can be designed to operate at any voltage up to 1500. There are a number of 33 cycle 1200-volt synchronous converters in successful operation, two of the most prominent installations being the 500-kw. machines furnished to the Portland, Oregon, Railway and the Michigan United Traction Co. The latter machines are insulated for 2400 volts, being operated two in series, and in a number of cases are arranged to supply both 1200 and 2400 volts.

When it is desired to obtain a voltage higher than about 600 volts and not above about 1500 volts direct current from a 60-cycle power transmission system, motor-generator sets are generally used because the desired voltage can be obtained from one machine and the synchronous motor can be arranged to give power-factor correction. Two synchronous converters connected in series, however, give a higher efficiency.

On account of the cost and the construction difficulties of the fields for self-excited generators having a voltage of 1200 or above, it is found advisable to separately excite the machines from a direct-connected 125-volt exciter. Since a separately-excited generator does not automatically drop its voltage on short circuit, the same as a self-excited machine, it is necessary to connect in series with the generator field a resistance that is normally short circuited by a contactor. The contactor is so connected to an attachment on the circuit-breaker that, when the circuit-breaker opens, the contactor also opens and thus the resistance is inserted in the generator field. By this action the voltage at the terminals of the generator is reduced. This arrangement has been used in a great number of cases and has met every requirement for successful operation.

For all voltages higher than about 1500, it is advisable to connect two machines in series when synchronous converters are used on account of the limitations of design, and when motor-generator sets are used on account of the cost. The machines furnished the Butte, Anaconda & Pacific Railroad, and the numerous interurban railways in Michigan, all consist of two 500-kw., 1200-volt generators or synchronous converters connected in series for obtaining 2400 volts. The series fields, commutating fields, and compensating windings of all machines are connected on the ground side. Where two

1200-volt synchronous converters insulated for 2400 volts are connected two in series, the low machine (the one on the ground side) is self-excited and the high machine (the one on the trolley side) is excited from the low machine.

It has been found advisable from a cost standpoint to build all high-voltage direct-current apparatus to carry 200 per cent overload for one minute and sometimes in the case of heavy traction work to design the apparatus to stand 200 per cent overload for five minutes and 100 per cent overload for half an hour. Where direct-current generators are required to stand 200 per cent overload for accelerating a train, it is usual to design them with compensating as well as commutating windings, thus almost entirely neutralizing the armature reaction.

At the time of the general adoption of commutating poles for 600-volt railway apparatus, it was found necessary to use a shunt in multiple with the commutating field windings in order to provide a means of adjustment for obtaining proper commutation. A simple resistance shunt was used with the first machines. With such a resistance shunt, it was found that the machines would either spark very badly or flash over under sudden large variations in load. An elaborate and exhaustive series of tests were made which demonstrated that it was necessary to supply a shunt having inductance as well as resistance in order that the current would divide properly during rapid changes in load as well as when the load was practically constant. Sometimes it is possible to design the commutating field so that a shunt is not required. A small amount of adjustment to obtain proper commutation can be obtained by varying the width of the commutating pole face slightly or by inserting non-magnetic shims between the commutating pole and the magnet frame. The reluctance of the commutating magnetic circuit can be changed by either of these methods.

It is believed that the equalization of the excitation, which will reduce the tendency to flash over on machines having commutating poles, will be obtained by bridging the commutating poles. Recently a big improvement was made in the operation of some commutating-pole synchronous converters by the addition of bridges. These machines are not provided with shunts. As a matter of convenience, it has been found advisable in general operation to supply commutating poles with a shunt winding which is excited directly from the machine or from the separate source of excitation, so that the commutation of the machine may be adjusted while in operation without being shut down.

Long years of experience have demonstrated that it is not necessary to provide any protection against short circuits, for 600-volt substation apparatus, beyond that given by the inherent impedance of the circuit and the circuit breakers. It is a well known fact that any 600-volt direct-current machine will flash over on short circuit but the resulting damage is not so great but that the machine can again be placed in service after the commutator has been cleaned up. There are no records available which would indicate the frequency with which short circuits occur. In some cases they are very infrequent and in others several occur each day. On a line in which short circuits are liable to occur quite frequently, it has been found that any trouble that has been experienced can generally be eliminated by extending the feeder a short distance from the substation before tapping it to the trolley. One case in particular is known where a substation, located adjacent to a car-barn, was subjected to frequent short circuits due to the peculiar overhead construction and the apparent inefficiency of the car-barn employees. The trouble was entirely eliminated by placing the car-barn circuit on a separate feeder in which was inserted a small amount of resistance.

Due to the greater safety factor in the design of all apparatus for 1200-volt operation, to the care with which the apparatus has been handled, or to the greater inherent impedance of the circuit as compared with 600-volt circuits, short-circuits are of comparatively infrequent occurrence. No records of any great damage being done are available and it is a fact that the writer cannot find that any serious complaints have ever been made of trouble from short circuits on any 1200- or 1500-volt substation apparatus. It has therefore not been found necessary to take special precautions to protect such equipment against short circuits. If trouble did occur, however, the natural step would be to do the same as has been done for 600-volt operation, i.e., to tap the feeder into the trolley system a short distance from the substation. In the initial operation of the 2400-volt Butte Anaconda & Pacific R.R. the switching yards at Anaconda were tied in directly with the main track. On account of the substation being located near the middle of the yard, short-circuits, which were very frequent, were very severe. The switching tracks were placed on a separate circuit in which the feeder was of considerable length; thus, enough resistance was included to reduce the severity of the short circuits. The operation since has been entirely successful.

The severity of short-circuits depends upon the distance at which they occur from the source of supply, i.e., they depend on the amount of impedance in the circuit. A short-circuit current near the terminals of a machine will amount to about twenty-five times normal current. However, as short-circuits near the terminals are very infrequent (usually taking place at quite some distance from the substation) there is enough impedance in the circuit to reduce the short-circuit current to from 12 to 15 times normal. Such values will do no great amount of damage beyond slightly burning the brush-holders and somewhat blackening the commutator. If short-circuits are very frequent, it would probably be necessary to tap the feeder into the trolley at such a distance from the substation that the current will be limited to eight or ten times normal, as the damage to a machine flashing over at this load would be slight.

Comparison of the short-circuits on 600-volt apparatus with those on 1200- and 1500-volt, shows conclusively that less damage done is to the higher voltage apparatus. The damage seems to be somewhat inversely proportional to the voltage, i.e., it appears that the damage done varies as the volume of the current which is, of course, independent of the voltage. In general, it might be stated that high voltage apparatus is slightly more susceptible to flashing over than 600-volt apparatus, especially so where one machine is used to obtain 1200 or 1500 volts because, in the design of this apparatus, it is generally necessary to use narrower commutator bars and higher commutator speeds than are used for 600-volt apparatus; thus the flashing distances are shorter. As previously stated, however, the consequences which result from this increased tendency of higher voltage apparatus to flash over need not be seriously considered.

Very serious consideration has been given to the question of introducing reactances in feeder circuits to prevent the current from rising to a greater value than eight or ten times normal before the circuit breaker opens. Calculations and a thorough study of this indicate that the intentional introduction of reactance is not advisable, on account of the excessive cost and the space occupied and because of the inductive kick which would have a tendency to cause the arc to hold across the breaker contacts. It is believed that it would be preferable to introduce into the supply circuit a resistance which will be normally short-circuited by a quick-acting mechanism that will automatically open and place the resistance in circuit before the current reaches a dangerous value.