

Modernization of a System of Protecting Adjacent DC Traction Network Feeders

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Abstract—The partitioning of railroads electrified on dc is done with the help of insulating air gaps (IAGs). When the pantograph collector of an electric locomotive crosses the branches of an IAG, an increment in current occurs in the feeder of the traction network entered by the electric locomotive. In these cases, the non-selective operation of a high-speed circuit breaker (HSCB) results in its false response, disconnection of the traction network power supply area, and, ultimately, stops the train. To preserve the reaction of the protection to a remote short-circuit and avoid false tripping in circuit-breakers, an interlocking circuit is proposed that prevents the tripping of HSCBs of adjacent dc traction network feeders at an instantaneous increment in current.

Keywords: traction power supply system, dc, feeder protection, insulating air gap, catenary system, burnout

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The principle of partitioning lies at the basis of the catenary system of electrified railroads. Direct current electrified railroads are divided in sections with the help of insulating air gaps. The protection of IAG branches against the influence of electric arc has long been an issue in transport electrical engineering. At present, the burnout of IAG conductors is commonplace even with the availability of various protective structures.

For the circuit of supplying power to an electric locomotive from two IAG contact conductors of two catenary sections, see Fig. 1.

When the electric locomotive's collector pantograph is bridged by a slide, an increment in current occurs under the current of the IAG branches (position 1 in Fig. 2) in the feeder of the traction network entered by the electric locomotive. In these cases, the nonselective operation of high-speed circuit breakers causes false responses, disables the traction network feed zone, allows the energized electric locomotive to enter the disconnected zone, produces an electric arc between the pantograph collector and the IAG branch, burns out the overhead line, and, as a consequence, stops the train. It should be noted that the potential cause of the tripping of HSCBs is determined by taking oscillograph records of changes in the traction network current over a long period (transitional processes in the current and voltage of the traction network feeder right before and during the opening).

At the moment that the pantograph collector and the IAG branch (position 2 in Fig. 2) left by the elec-

tric locomotive are opened, an electric arc sparks between them and burns out the traction network's conductors and structures. The arcing is very stable.

The system of protecting the adjacent feeders of the dc traction network against SC currents is actuated with the help of nonpolarized circuit-breakers and primary protection sensors in the form of relay-differential shunts (RDSs) [1]. These devices allow switching off the TNF at a low value of fast changing current. This is exactly why RDSs are used as selective devices for protection against low SC currents; however, this same device causes false responses of HSCBs when an energized electric locomotive enters the IAG. Consequently, it is this property of the RDS that produces the electric arc burning out the catenary conductors [2].

This occurs as described below (Fig. 3). Assume that electric locomotive 10 consuming current I_E enters IAG 7 from left to right. When this locomotive reaches position II, the IAG is overlapped by pantograph collector 9; as a result, current I_E earlier supplied from the buses of traction substation 1 along left feeder Φ_{lf} through circuit breaker 2 and RDS 4 begins to rapidly redistribute between the left and right connected feeder Φ_{rh} (Fig. 3a). With this, current $I_{\Phi_{lf}}$ sharply drops and $I_{\Phi_{rh}}$ rises. This is equivalent to the decrease in current in the left feeder ($-\Delta I_{\Phi_{lf}}$) and the increase in current in the right feeder ($+\Delta I_{\Phi_{rh}}$). With an appropriately adjusted RDS, the change in the right feeder current trips circuit-breaker 3 due to the actuation of RDS 5 for the change in current (electric locomotive position III, moment t_{III} , Fig. 3a). From now on, the

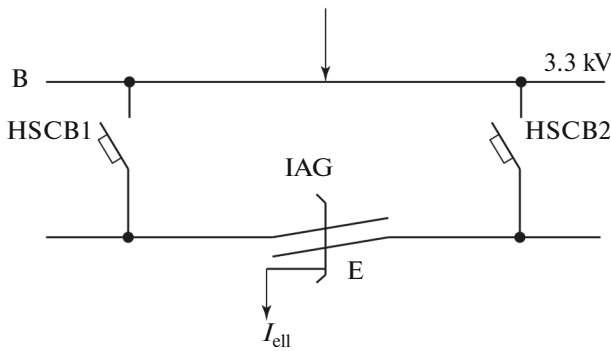


Fig. 1. Circuit for supplying power to an electric locomotive from two conductors of IAGs of two sections in the catenary system: B is the buses of the 3.3-kV substation; IAG is the insulating air gap; HSCB1 and HSCB2 are the respective high-speed circuit-breakers of the traction network’s left feeder (TNF), which feeds the branch left by the electric locomotive, and the right TNF entered by the electric locomotive; ELL is the electric locomotive in the form of a pantograph; and I_{ell} is the electric locomotive current.

electric locomotive is powered only along the left feeder through the left branch throughout the entire remaining period of motion along the IAG. As a result, when the pantograph collector leaves the left branch (position IV, moment t_{IV} , Fig. 3a), an electric arc ignites between the pantograph collector and the contact conductors or the left branch thread and burns them out (position Va, moment t_{Va} , Fig. 3a). The arcing is maintained by the inductance including the ones of the primary feeder, substation, and loop: the left feeder conductor is the suction line of the traction substation with a smoother reactor.

If the HSCB of the right feeder is not tripped in position III after the first touching of the IAG branches by the electric locomotive pantograph collector, the probability of this trippings can be even higher right after the pantograph collector leaves the

branch fed from the left (position IV, moment t_{IV} , Fig. 3b), when the second increment in current occurs during the ultimate transmission of the right feeder’s entire load current I_E . The RDS current setting of the right feeder will significantly decrease by the time due to the flow of steady-state current $\Delta I_{\phi_{rh}}$ before the second increment.

This transmission of current is normally attended by an arc between the pantograph collector and the left feeder branch. The arcing is maintained through the inductance of the loop formed by the conductors of the right and left feeders, air gap, and substation buses. If the right TNF is disconnected before arc extinction—that is, before the natural transmission of current of the right feeder finishes—entire current I_E begins flowing through the still unextinguished arc. Furthermore, the inductance maintaining the arcing from then on is much greater and includes the inductances of the primary supply mains, substation, and loop: the left feeder conductor is the suction line of the traction substation with a smoother reactor. As a result, the left branch conductor are burned out at moment t_{Vb} (Fig. 3b).

The ideal mode of transmitting current from one branch of the IAG to the other is shown for clarity in Fig. 3c. The transmission is performed in two phases called moments t_{II} and t_{IV} , without any opening of the HSCB of the right feeder. The arc length increases proportionally with time for the former depends on the electric locomotive speed (Fig. 4):

$$l_{arc} = f(t),$$

$$l_{arc} = 1.57x = V/3.6t \times 1.57,$$

where x is the distance covered by the electric locomotive’s pantograph collector per time t .

The analytical and experimental studies of short-circuit current in the catenary system are described in [3], where it is shown that the discrepancy between the exponential analytical dependence and its linear experimental counterpart is from 2 to 3%. For this rea-

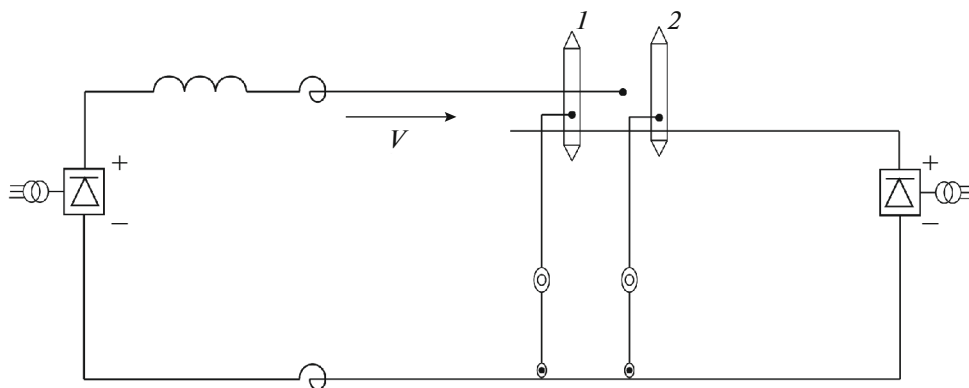


Fig. 2. Electric locomotive’s motion route along the IAG branches.

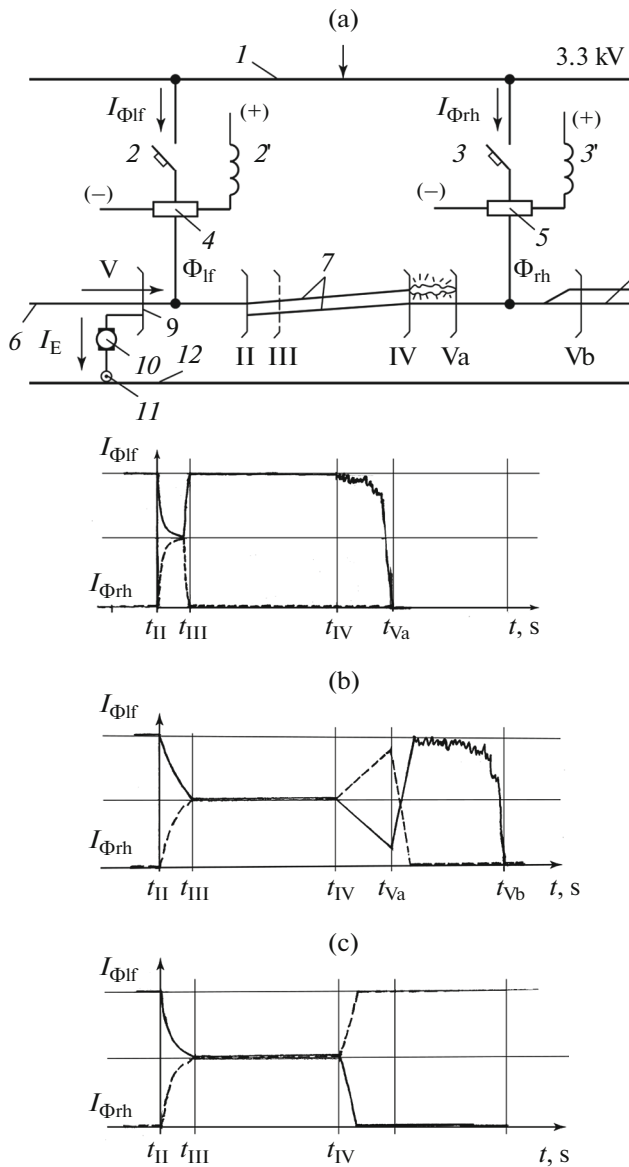


Fig. 3. Electric locomotive's motion in energized mode along the IAG branches.

son, the dependence of the voltage in arc column e_{arc} on time t is taken for linear.

It should be noted that, the higher the electric locomotive's speed and the more current it consumes, the greater the possibility that the HSCB is tripped will be, the longer the arc will be, and, therefore, the more serious the effects of emergencies will be.

Thus, the false responses of the RDS at an instantaneous rise in current are a major cause of burnouts of IAG conductors. Consequently, the cause of burnouts can be eliminated only by eliminating the false responses of the RDS.

The imperfection of the protection provided with the help of the VAB-49 circuit breaker with RDSs with

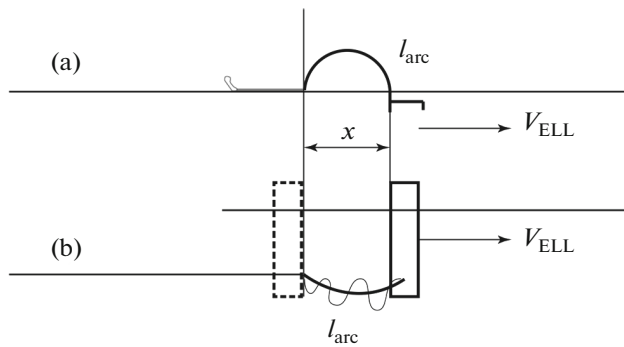


Fig. 4. Relocation of the electric locomotive current collector from the powered to the unpowered branch of the IAG: (a) lateral-side view and (b) top view; l_{arc} is the arc length, and V_{ELL} is the electric locomotive speed.

specific features makes it necessary to upgrade this protection so as to preserve its reaction to a remote SC and avoid any response when the energized electric locomotive enters and leaves the IAG.

To resolve this issue, it is proposed to use a circuit of special blocks preventing the HSCBs of the traction network's adjacent feeders from tripping at an instantaneous current increment. It is proposed to upgrade the installation of ancillary coils 11 (Fig. 5) on the magnetic wires of the RDS of these feeders. The leads of these coils must be connected through the interlocking circuit proper. The blocking is activated upon the synchronous occurrence of current increments of equal value in the network, that is, the negative increment in the TNF left and the positive increment in the TNF entered by the electric locomotive.

The approach to constructing a protective system based on available electrical equipment using the RDSs of adjacent TNF is considered below. This protection is designed as a circuit of blocking unauthorized responses of HSCBs of adjacent TNFs.

The interlocking circuit (Fig. 6) consists from non-polarized HSCBs 3 and 4 and an upgraded RDS (RDS(UP) with ancillary coil (ANC) 11. In this circuit, the first ANC leads of each feeder are interconnected, whereas the other ANC leads are connected to voltage relays 5 and 6, respectively, with NC contact elements installed in parallel with the RDS (UP) of their feeder and the free leads of each voltage relay are interconnected.

The interlocking circuit works as described below. When the pantograph collector earlier moving from left to right along branch 7 at speed V touches IAG branch 8, current I_1 flowing through HSCB 1 and RDS(UP) 3 instantaneously changes (drops) by a certain value. It is obvious that right feeder current I_2 flowing through HSCB 2 and RDS(UP) 4 rises by the same value. The increments in current result in the induction of voltage in ancillary coils 5 and 6 of RDS(UP) 3 and 4, respectively. However, coils 5 and 6

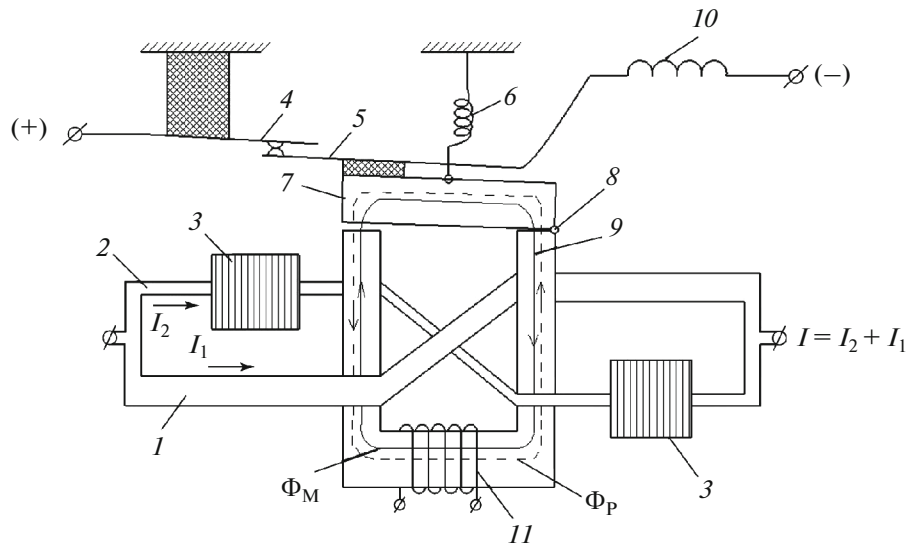


Fig. 5. RDS circuit: (1) is heavy-gauge bus, (2) small-gauge bus, (3) concentrated inductances as packets of iron, (4) stationary contact, (5) mobile contact, (6) orienting spring, (7) mobile part (armature) of the magnetic conductor, (8) axis, (9) stationary part of the magnetic conductor, (10) holding coil, and (11) extra coil.

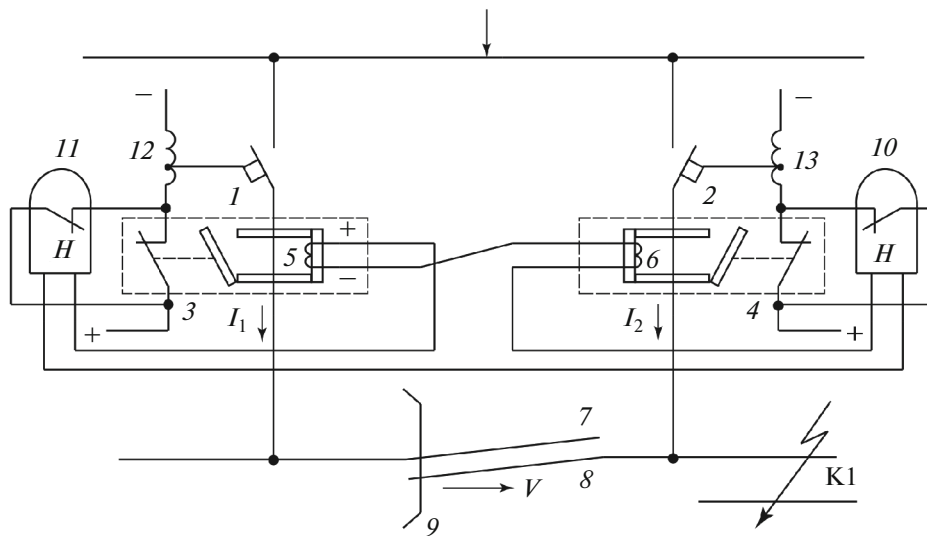


Fig. 6. Diagram of the blocking of an unauthorized response of the HSCBs in the adjacent traction network feeders.

are series-connected in such a manner that their aggregate voltage supplied to voltage relays 10 and 11 is theoretically equal to zero when the negative increment in current in one of the adjacent feeders is negative and the positive increment in current in the other is of the same value but positive: in this case, the output voltages of the ancillary coils compensate (neutralize) one another. For this reason, if the voltage reasons set for both relays 10 and 11, are higher than zero but lower than the voltage induced in the ancillary coil of each RDS(UP), none of these relays will respond in the specified situation. Despite the response of

RDS(UP) 4, there will be no tripping due to an increment in current or even the separation of the pantograph collector from the IAG branches and the response of the RDS(UP) of any of HSCBs 1 and 2, as well as due to an increment in current and, respectively, the opening of the CB contacts, because circuit-breaker control coils 12 and 13 will continue being streamlined by the current through the NC contact elements of corresponding relays 10 and 11. Thus, potential burnout of the IAG contact conductor will be prevented.

On the other hand, if an SC occurs in the branch of the traction network of the right feeder entered by the electric locomotive in the energized mode (for example, in point K1), HSCB 2 will deactivate this short-circuit because, in this case, RDS (UP) 4 will respond and open its NC contact elements. Both voltage relays, 10 and 11, will synchronously respond and open their NC contact elements, because, in this case, the voltages supplied to the relays will be high and exceed their settings and amount to one-half of the voltage induced in ancillary coil 6 of RDS (UP) 4 of the feeder branch where the SC occurred (in this case, we mean the branch of the traction network of the right feeder). However, there will be no tripping of the HSCB of the traction network's other feeder for, when the contacts of its voltage relay 11 open, control coil 12 of HSCB 1 will continue being powered through the NC contact elements of its RDS (UP) 3.

We have developed a test prototype of the device for blocking unauthorized responses of the high-speed circuit breakers of the adjacent feeders of the dc traction network and submitted it to full-scale testing at an active traction substation. The method of dealing with the causes of electric arc ignition with the help of elec-

tric circuits not affecting the design and weight of the overhead catenary has confirmed the new device's superiority to mechanical fixtures.

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