

MODELING PROCESSES IN THE TRACTION NETWORK AND THE PARAMETERS FOR CONNECTING THE INTERLOCKING

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ABSTRACT

The process of passing a train under the current along the branches of an insulating air gap of a DC traction network is studied, the reasons for disconnection of the branch to which the train enters are shown. To solve the tasks of increasing productivity and reducing costs in the work of

electrified railway transport, a scheme for blocking the unauthorized operation of a high-speed switch is proposed. Using the modeling of the process of current variation in the network, the parameters of the additional coil of the magnetic circuit of the relay-differential shunt for connection of the locking device are determined.

Keywords: railway, traction network, relay-differential shunt, blocking scheme, simulation modeling, coil parameters of magnetic circuit.

Background. Electrified railway is a system of complex technical structures. One of the indicators of their effectiveness is the increase in the capacity of the lines. Particular importance in this case is attributed to the state of the traction network. After all, with some disruptions in traffic, unexpected stoppage of one rolling stock, there is also a delay of other trains on the haul. And it is important not just to determine the reasons for the stop, but also to know all possible extensions.

Objective. The objective of the author is to consider modeling processes in the traction network and the parameters for connecting the lock.

Methods. The author uses general scientific and engineering methods, evaluation approach, mathematical apparatus.

Results.

Protection of currents against short-circuit

Constant influence of meteorological factors, mechanical and thermal loads, electromagnetic fields, sparking leads to the failure of traction network elements, accompanied by a decrease in its resistance with a sharp increase in current, which leads to short circuits. In the emergency mode of short-circuit, which occurs for a variety of reasons, the operation of the traction power system is disrupted, and there are disruptions in movement of trains.

Short-circuit currents that occurred near the traction substation (for so-called close short circuits) can exceed the value of normal load currents by 20–40 times. Such values, even with a very short duration, can result in the destruction of switching devices and various structures as a result of dynamic action.

At the same time, short-circuit currents that originated at a considerable distance from the traction substation (the so-called remote ones) are, in some cases, so small that their value does not reach the level of conventional load currents. If the short-circuit current is applied for a long time, the heat generated at the place of contact with the grounded element can cause the contact wire to burn, especially when an electric arc occurs.

In addition to the emergency operation modes of the traction network, there are regular situations in which the parameters of the currents and voltages of the feeders of the contact network are close in value to the short-circuit parameters.

In all these cases, the current feeder current varies in a jerky manner, which can lead to a non-selective operation of the fast-acting feeder switch, power-off, train shutdown, arcing and burnout of the contact wire.

Traction loads in the normal mode, in contrast to the loads of other consumers of electricity, are characterized by special properties inherent only to them: their importance is constantly changing, and the changes are of an accidental and increasing nature. Similar changes in current are observed in emergency modes.

The commensurability of the values of currents in various situations indicates the difficulty in their classification. In such conditions, the operation of short-circuit protection devices in a traction DC network acquires a certain specificity.

It should be noted that in order to determine the possible reason for the disconnection of feeder-type high-speed circuit breakers, it is necessary to oscillograph for a long time the process of current variation in the traction network (transient processes of current and voltage of the feeder immediately before and during disconnection).

One of the main directions of the research is the determination of a set of parameters in the work of a traction network using the modeling of processes and based on the data obtained, the construction of characteristics in order to predict the properties and the modernization of individual protection devices.

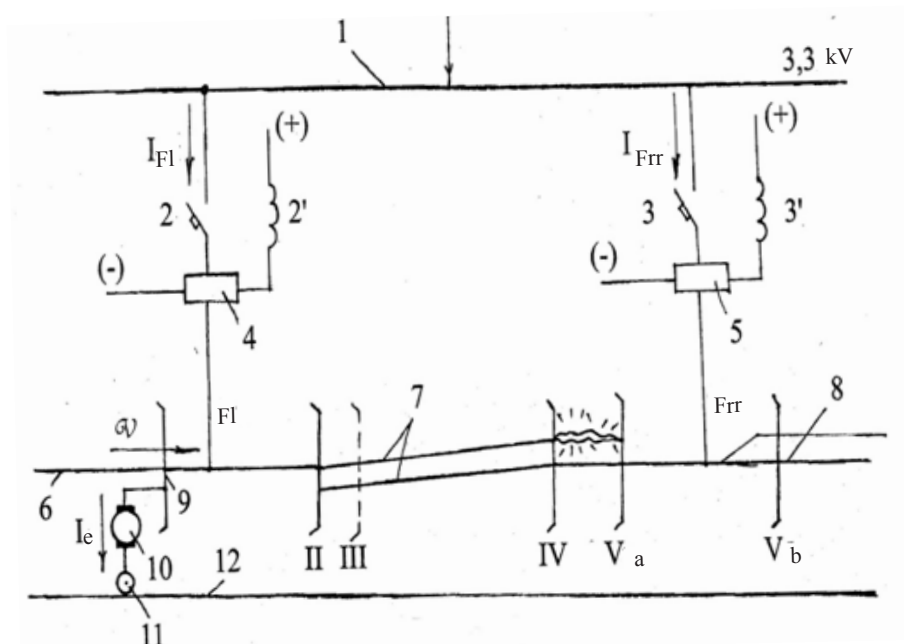
This problem is known and it is devoted to the works of many scientists and organizations interested in the DC traction network and its reliability. A wide range of research is, in particular, the Swiss company Secheron [1].

Characteristic of relay-differential shunts

Current jumps in the network occur for various reasons. Let us consider one of them: during the closing of the electric locomotive under the current of the branches of the insulating air gap of the DC traction network by the current collector. The load current, delivered earlier on the left feeder, along which the electric locomotive was moving, is redistributed between the given and the connected right feeder (Pic. 1).

There is a negative current jump on the left feeder, along which the electric locomotive moved, and the same positive jump on the connected right feeder. Pic. 2c shows the ideal process of redistribution of currents between feeding feeders.

A sudden change in current leads to the activation of high-speed devices of adjacent feeders and unauthorized disconnection of the power zone (Pic. 2a, b). Protection of adjacent DC traction feeders is provided by unpolarized switches and primary protection sensors – relay differential shunts (RDS). Due to the actuation of the relay-differential shunt in response to the current jump,

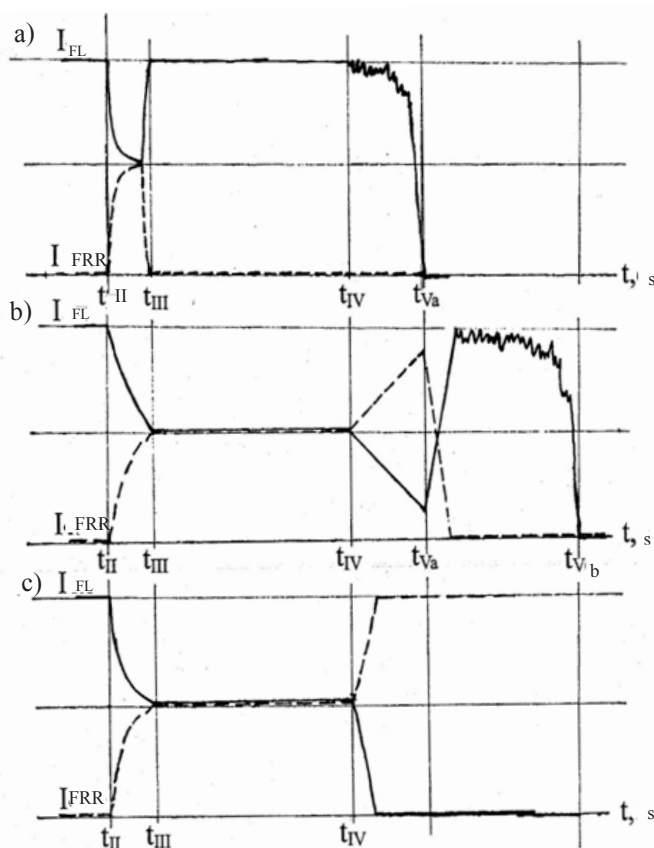


Pic. 1. The process of the movement of an electric locomotive along the branches of an insulating air gap.

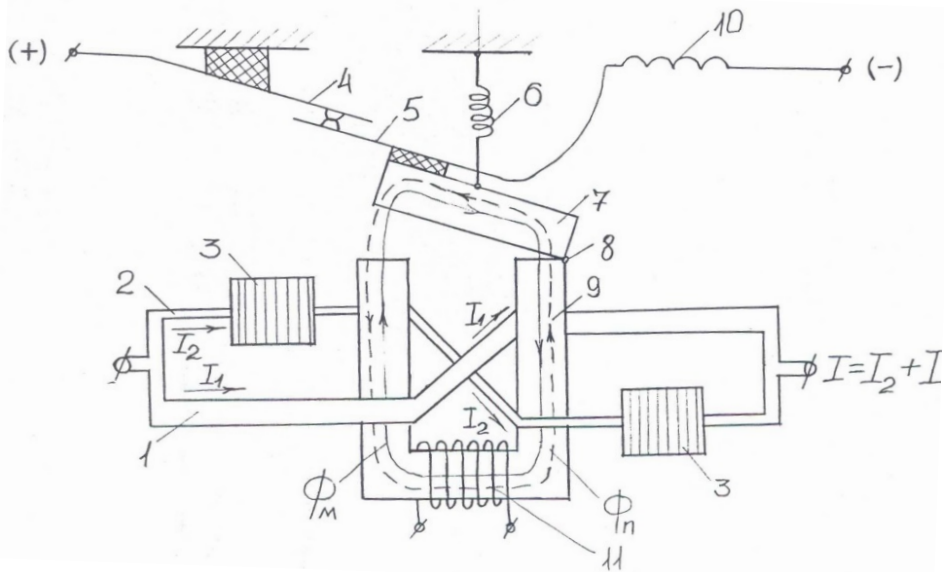
the cut-off of the branch of the right feeder, to which the electric locomotive drives under the current, can occur at the moment of t_{IV} touching the collector of the branch (Pic. 2a). If there is no switch-off at the time t_{IV} , then with even greater probability, for

the same reason, it will occur at the time t_{IV} of the movement of branch of the left feeder, along which the electric locomotive moved (Pic. 2b).

The relay-differential shunt is a magnetic core 9 (Pic. 3) with an anchor 7. Inside the magnetic circuit,



Pic. 2. The process of redistribution of currents along the branches of the supply of an insulating air gap.



Pic. 3. Diagram of a relay-differential shunt with an additional coil.

tires 1 and 2 are unequal in cross-section, and on the bus of a smaller cross-section 1, packets with iron 3 are placed. The anchor, with the movable contact 5 fixed on it, spring 6 to the stop with the fixed contact 4 (the contacts are normally closed). The difference in currents in the buses caused by a change in the current in the bus causes in the magnetic circuit a magnetic flux F_m of such a force that, breaking the force of the spring tension, attracts the armature to the magnetic circuit, disconnecting the movable and stationary contacts. The primary protection sensor is triggered and the feeder is disconnected.

If we assume that the current increases according to an exponential law (which is close to reality), then the characteristics of the relay operation are described by three parameters:

- the value of the steady-state current preceding the increment (jump) of the current I_{1*} ;
- magnitude of increment (jump) of the current ΔI_{1*} ;
- time constant of the increment (jump) of the current T_1 .

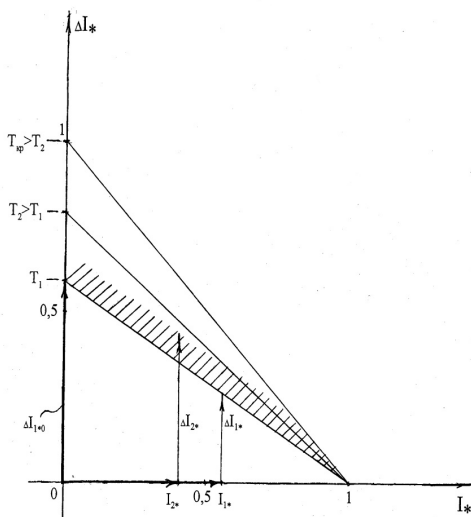
Pic. 4 (the values of I_{1*} and ΔI_{1*} are given in relative units), it is seen, for example, that when the previous load on the feeder I_{2*} and the subsequent current increment ΔI_{2*} , the relay will work if the time constant of the current increment is equal to T_1 (the range of the relay for jumps with time constant T_1 is shaded) and will not work if the time constant of the jump is T_2 .

That is, with a constant time of the network T_1 independent of I_{1*} , the switch only operates from a current jump of magnitude ΔI_{1*} or only from a steady-state current value ΔI_{1*} , if it was preceded by a steady-state current I_{1*} .

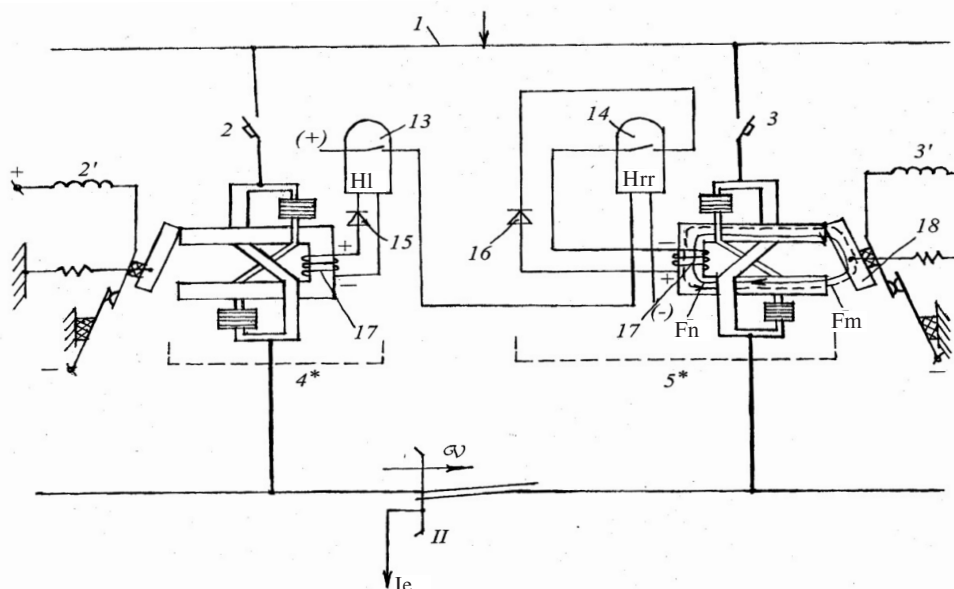
The value of I_{1*} is static, and the value ΔI_{1*} is the dynamic settings of the switch. The dynamic setting ΔI_{1*} depends on the network time constant T_1 .

Under real conditions, the time constant of the network T_1 depends in a complex manner on the steady-state value of the current I_{1*} . Therefore, when constructing the circuit breaker response characteristic for a certain section, it is necessary to know how its dynamic set point changes as the network time constant T_1 changes. In practice, the modeling of processes in a traction network or on some technical element is widely used. In particular, the graphs of current changes in the traction network, obtained in this way, serve as the basis for further device upgrades.

The nature of the current rise in the network and the time constant of the network are the objects of the Secheron study [1], which is confirmed by the resulted characteristics – the results of dynamic modeling of the DC network by the developed software. The basis is software modeling for calculating the power system, voltage drop along the line, calculating the optimal parameters of high-speed switches, creating a protection scheme.



Pic. 4. Characteristic of the operation of the relay-differential shunt.



Pic. 5. Blocking scheme using a voltage relay.

Causes of false disconnections

The relay-differential shunt [2] reacts differently to slow and rapid changes in the current of the feeder, and its operation in the transient mode is determined by the above three parameters (in relative units).

This device allows to disconnect the feeder of the traction network at a low value of the rapidly changing current. However, the same property of the RDS also causes false disconnections of the feeder breakers at the entrance to the insulating air gap of the rolling stock under the current. Starting from the moment of separation of the electric locomotive current collector from the branch of the insulating air gap fed by the left feeder and entering the disconnected zone of the right feeder, the movement of the electric locomotive occurs due to the support of power only from the left feeder, causing the appearance of an arc.

The reason for the overburning of wires of the insulating gap is the false operation of the relay-differential shunt by the current jump and, consequently, the cause of the burns can be eliminated only by eliminating false disconnections. There are two ways to solve the problem.

One of them is to eliminate the response of the relay-differential shunt to the increments (jumps) of the current. However, this way is undesirable, because at the same time the possibility of the relay to react to small short-circuit currents is eliminated, which can lead to even more unpleasant consequences – the annealing of the wires of the contact network.

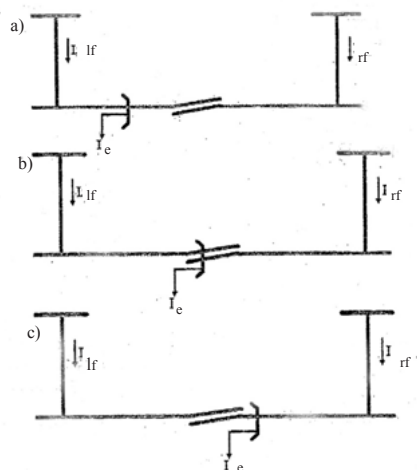
The other way seems more effective. It involves the introduction of special interlocks preventing disconnection from the current jumpers of adjacent feeders feeding the branches of the insulating air gaps of the DC traction network.

Scheme of the modernized shunt

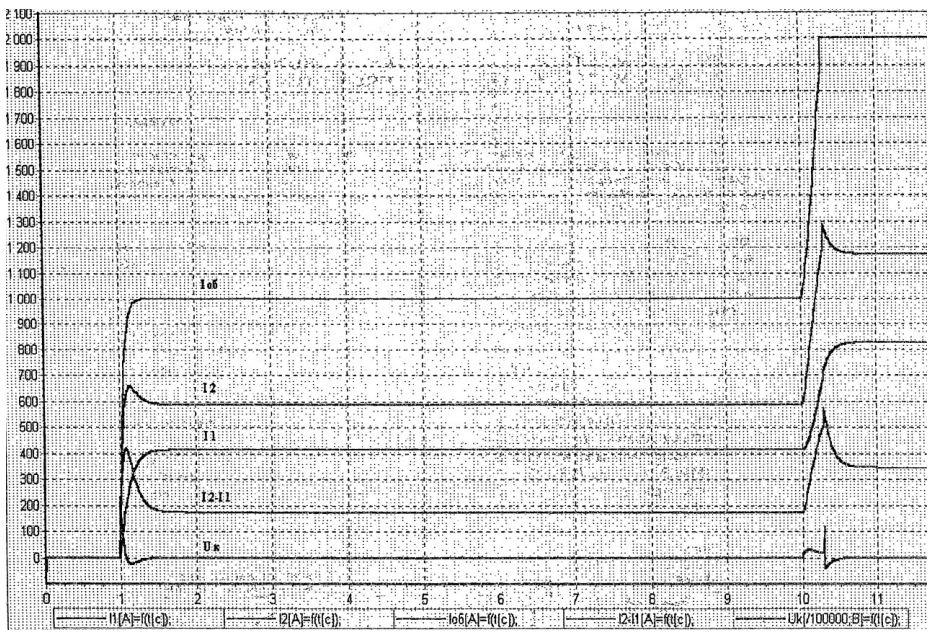
In the scheme (Pic. 3), modernization consists in the addition of an additional coil 11 on the magnetic circuit of the relay-differential shunt. The activation blocking is achieved by connecting the locking circuit and damping the magnetic flux F_m in the magnetic circuit of the relay-differential shunt opposite to F_n (Pic. 5).

When the current collector touches the electric locomotive of both branches of the air gap, the current jumps equal in magnitude will occur – negative ($-\Delta I_f$) on the left feeder and positive ($+\Delta I_f$) on the right. A negative current jump on the left feeder induces a voltage on its additional coil, which forces the voltage relay of the left feeder 13 to work, since the direction of the current in the coil circuit coincides with the conductive direction of the diode 12. As a result, the voltage relay closes its normally open contacts through which the voltage of the operative direct current to the coil of the voltage relay of the right feeder 14. The latter operates and closes its contacts with an additional coil 11 of the relay-differential shunt through the feeder diode.

At the same time, a positive current jump on the right feeder will induce in its additional coil a voltage which direction coincides with the conducting direction of the diode 15. As a result, a current begins



Pic. 6. Stages of modeling the passage of an electric locomotive along the branches of an insulating air gap.



Pic. 7. Dependences of the currents in the buses of the relay-differential shunt and the voltage in the additional coil as a result of simulation.

to flow through the additional coil. The flux of P_n in the magnetic circuit of the relay-differential shunt feeder, created by this current, is, in accordance with Lenz's law, the opposite of the flux F_m produced by the positive current jump $+ \Delta I f_3$ in the magnetic circuit of the shunt of the right feeder. Therefore, the total flux of the magnetic circuit ($F_m - F_n$) will be close to zero and the primary protection sensor of the right feeder will not react to a positive current jump, i.e. its false triggering from the current jump will be eliminated.

The value of the feeder current jump $-\Delta I f_1$, which causes the indicated operation of the device, is regulated by the value of the voltage setting of the voltage relay of the left feeder.

This device with its characteristics allows not to disconnect the primary protection sensor from the

surge of the operational current while traveling along the branches of the insulating air gap of the current collector of the electric locomotive under the current, but at the same time ensures the shutdown of the zone in the event of a short circuit on it.

Modeling of electric locomotive motion

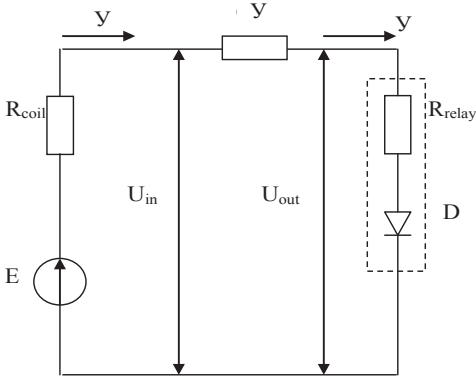
The operation of the relay-differential shunt is caused by the appearance of a magnetic flux in its magnetic circuit, which depends on the difference in currents in its unequal cross-sectional buses, created by a change in the current in the network.

Current jumps in the network and the buses of relay-differential shunts of adjacent feeders during the motion of the current collector of the electric locomotive along the branches of the insulating air gap of the DC traction network have the character of a transient process. Simulation of the process is formed by constructing three consecutive stages [3]:

- movement of the current collector of the electric locomotive along the branch of the traction net fed by the left feeder (Pic. 6a);
- movement of the electric locomotive along two branches of the insulating air gap and feeding it to the left and right feeders (Pic. 6b);
- separation of the current collector of the electric locomotive from the branch of the insulating air gap fed by the left feeder and the movement of the current collector of the electric locomotive along the branch of the traction net fed by the right feeder (Pic. 6c).

The purpose of the simulation is to determine the dependence of the current change in the branches on time at a particular time using a common electrical circuit of the network section. All values of the scheme are taken close to real ones or are calculated.

If the switch of the right feeder is switched off at the moment of exit of the electric motor pantograph from the branches of the insulating air gap (Pic. 6c), an electric arc appears between the pantograph and the branch.



Pic. 8. Scheme of connecting an additional coil to the blocking scheme.

The result of the simulation is the dependence of the currents in the buses of the relay-differential shunt and the voltage in the additional coil as a function of time during the entire simulation period (Pic. 7), where:

I_{ob} is feeder current;

I_1, I_2 – are currents in the buses of the relay-differential shunt of smaller and larger cross section, respectively;

$I_2 - I_1$ is difference of currents in the buses of the relay-differential shunt;

U_k is voltage in the additional coil of the relay-differential shunt.

The magnitude of the voltage induced in the additional coil of the relay-differential shunt depends on the difference in currents flowing through its busbars. Based on the obtained data, the parameters of the blocking scheme were developed from false trips of high-speed switches of adjacent feeders equipped with relay-differential shunts.

Coil settings for interlocking

Based on the results of the simulation of the transient process and the obtained dependences of the currents and voltage on time, the voltage value of one turn of the additional coil located on the magnetic circuit of the relay-differential shunt is:

$$U_{iv} = e_{iv} = 25 \cdot 10^{-5} \text{ V.}$$

Connection of the outputs of the additional coil of the relay-differential shunt is made to the blocking scheme using a 5P14A type voltage relay with parameters $R_p = 28 \text{ Ohm}$, $I_p = 25 \text{ mA}$, $U_p = 0,7 \text{ V}$.

We take the value of the resistance of the additional coil significantly exceeding the resistance value of the voltage relay ($R_{coil} > R_p$). Then, using a coil with an amount of turns $w = 1$ from a copper wire of 0,1 mm in diameter and a turn length of 15 cm (in accordance with the dimensions of the magnetic circuit), the resistance and current have the following values:

$$R_{iv} = R_{wire} \cdot l_{wire} = 0,34 \text{ Ohm,}$$

$$I = e_{iv} \cdot w / R_{iv} \cdot w = 8 \text{ mA.}$$

The required current value of 25 mA is not provided.

For the operation of the voltage relay, it is necessary to increase the current in the additional coil by means of an operational amplifier and a current divider, which, with an increased current of the additional coil, ensures the operation of the selected amplifier with its parameters.

According to the previously calculated parameters, we select an amplifier UD6 having an input resistance $R_{in y} = 1000 \text{ Ohms}$ and an input current $I_{in y} = 5 \cdot 10^{-8} \text{ A}$, an output resistance $R_{out y} = 50 \text{ Ohm}$ and an output current $I_{out y} = 25 \cdot 10^{-3} \text{ A}$.

To determine the number of coil turns, the equation becomes:

$$w e_{iv} = R_{iv} w I_{in y} + I_{in y} R_{in y}, \text{ hence}$$

$$w = I_{in y} R_{in y} / e - R_{iv} I_{in y} = 0,2.$$

That is, one turn is enough to ensure the amplifier's performance in terms of incoming characteristics.

According to the received data it can be said that the voltage value at the terminals of the additional coil, equal to the input voltage of the amplifier, is small. And the induced voltage from equipment installed

near the installation is comparable in magnitude to the calculated voltage of one turn: $e_{iv} \approx e_{ind}$. For the functioning of the circuit, it is necessary to ensure the following condition: $e_{iv} > e_{ind}$, which can be achieved by increasing the number of coil turns, that is, the following condition must be fulfilled:

$$e_{iv} w > e_{ind}.$$

For the final determination of the number of turns of the additional coil sufficient for the operation of the circuit, let us set the ratio $R_{in y} = R_{2d} = 1000 \text{ Ohm}$:

$$w = (R_{in y} / R_{2d} + 1) \cdot R_{in y} / e_{iv} \cdot (100 R_{2d} + R_{in y} R_{2d} / R_{2d} + R_{in y}) \cdot I_{in y} = 40 \text{ turns.}$$

It can be concluded from the calculations that in order to achieve interference resistance of the proposed scheme, it is sufficient to install an additional coil with a number of turns equal to 40 on the relay-differential shunt magnetic circuit.

Also, based on the simulation results, the number of turns of the additional coil creating the damping flux F_p in the magnetic circuit of the relay-differential shunt is determined.

Conclusion. When the train passes under the current along the branches of the insulating air gap, the voltage relay will operate in the key mode.

If there is a short circuit in the traction network, the additional coil remains open and the relay-differential shunt is activated in the operational mode, disconnecting the power zone where the emergency mode is fixed. In addition, it becomes possible not to set the set point, ensuring the selectivity of the protection.

The positive economic effect from the application of the blocking scheme has been proved by calculations [4], based on a reduction in the cost of materials and labor of repair teams previously spent on the restoration of wires and structures of insulating air gaps from electric arc burns.

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