POWER CONTROL OF SHUNT COMPENSATION INSTALLATION AT SECTION PILLAR

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ABSTRACT

The complexity of power control of shunt capacitive compensation installation at the section pillar of AC catenary has its causes and consequences, which are connected with the incompleteness of information on the traction load. It is proposed to assess the load degree of traction network and therefore control the compensation installation by voltage drop between traction substations and section pillar. The authors consider the possibility of increasing the accuracy of power control of shunt capacitive compensation installation by transmission of busbars' voltage data of 27,5 kV traction substations.

ENGLISH SUMMARY

Background. *Power control of shunt capacitive compensation installation (hereinafter-CI) at the section pillar (hereinafter- SP) of AC catenary is conducted to compensate reactive power and reduce the voltage loss. The complexity of the process is due to lack of information on the value of traction load in traction network of between-substations zone [1], and regulation is carried out see the voltage on SP. However, its level, unfortunately, does not reflect the load degree of traction network, since it depends on variable voltage of busbars of traction substation. That is the reason why power control of CI occurs with choice error concerning switch-on and switch-off moments. Hence there is a proposal to assess the load degree of traction network and, therefore, to adjust the power of CI on the basis of data of voltage loss between the traction substation and SP.*

Objective. *The objective of the authors is, by an example of the real section of the traction power supply, to consider a possibility to improve the accuracy of power control of shunt capacitive installation at section pillar by transmitting the data on voltage of busbars of 27,5 kV traction substations.*

Methods. *The authors use mathematical method, specific electric engineering calculation methods and techniques, computer simulation.*

Results.

Principle of installation control

Control of shunt capacitive compensation installation is shown in Pic. 1, in which the following notations are used: 1 – auxiliary contact of CI switch; 2 – receiver subset of SP remote control; 3 – time relay. Characteristics of voltage of section pillar enters the calculated block from transformer (hereinafter- T).

Active power losses in the traction network with CI at the section pillar in matrix form are equal to

$\Delta P = I^t R I,$ (1)

where $I = |I_1, I_2, \ldots I_k|$ *is a vector column of currents of electric rolling stock* ($I_1, I_2 \ldots\ldots$) *and CI* (I_k);

R – square matrix of nodal active resistances of catenary (nodes 1,2,… k);

I^t *– conjugate and transpose current value.*

Minimum power loss is determined from (1) by calculating the derivative dP/dI_k *and equating it to zero.*

As a result, we obtain a condition of minimum loss in traction network:

$I_k R_{kk} = \sum I_{pi} R_{ik},$ (2)

that is, the voltage loss to CI (node k) in the nodal active resistance R_{kk} *from current CI should be equal to voltage losses of reactive currents* I_{pi} *of traction load to CI.*

Nodal resistances R_{kk}, R_{ik} *and* X_{kk} *are easier to calculate using a software program RAST-05K [2].*

At the section pillar voltage is measured by a transformer T, which defines U_{sp}.

Then the voltage loss in traction network from a traction substation and to SP is equal to

$\Delta U_{sp} = U_o - U_{sp},$ (3)

where U_o *is voltage on busbars of 27,5 kV traction substation.*

If CI is turned on at SP, the voltage losses to SP are equal to

$\Delta U_{sp(k)} = U_o - U_{sp(k)},$ (3a)

where indices ($_k$) *indicate that CI is on.*

Voltage loss in traction network ΔU_{sp} *of traction load is equal to [2]:*

$\Delta U_{sp} = \sum (I_p R_{ik} + I_q X_{ik}) = \sum I_i (\cos\phi \, R_{ik} + \sin\phi \, X_{ik}) =$
$= (\sum I_i R_{ik}) (\cos\phi + q \sin\phi) = (\sum I_i R_{ik})\, a.$ (4)

Here I_p, I_q *are active and reactive components of currents of traction load (we state that cosϕ of traction load (of all electric locomotives) are the same). Expression* $(\cos\phi \, R_{ik} + \sin\phi \, X_{ik}) = Z_{ik(c)}$ *is usually called a composite resistance [2], it can be used in the calculation of traction network with the installation of shunt capacitive compensation in the first approximation by the first harmonic, as specified in [2].*

If $Z_{ik(c)}$ *is divided by* R_{ik}, *then the value* $a = Z_{ik(c)}/R_{ik} = (\cos\phi + q \sin\phi)$ *is called a relative value of the composite resistance. As for practical calculations cosϕ of all electric rolling stock is taken identical, and the ratio* $q = X_{ik}/R_{ik}$ *is const, then for each substation zone we can assume that a = const.*

As seen in (4), the loss of voltage $\sum I_i R_{ik}$ *can be determined by measured loss of voltage* ΔU_{sp}:

$\sum I_i R_{ik} = \Delta U_{sp} / a.$ (5)

As for the reactive current CI cosϕ = 0, and sinϕ =1, voltage losses to CI of its reactive current, particularly during unilateral power supply of SP by traction network, will be equal to $I_k X_{kk}$, *i. e. when measured current is* I_k *it is possible to calculate voltage losses* $I_k X_{kk}$ *at a known resistance* X_{kk}.

As for voltage losses $\sum I_{pi} R_{ik}$ *from reactive traction loads, they are calculated by measured voltage losses from the traction load without CI:*

$\sum I_{pi} R_{ik} = \Delta U_{sp} (\cos\phi) / a.$ (6)

Thus, to calculate $\sum I_{pi} R_{ik}$ *it is necessary to measure* ΔU_{sp}, *which must be multiplied by cosϕ/a. Values* X_{kk}, R_{kk} *and* R_{ik} *for each between-substation zone are easier to determine with the program RAST-05K.*

If CI is on, voltage losses are:

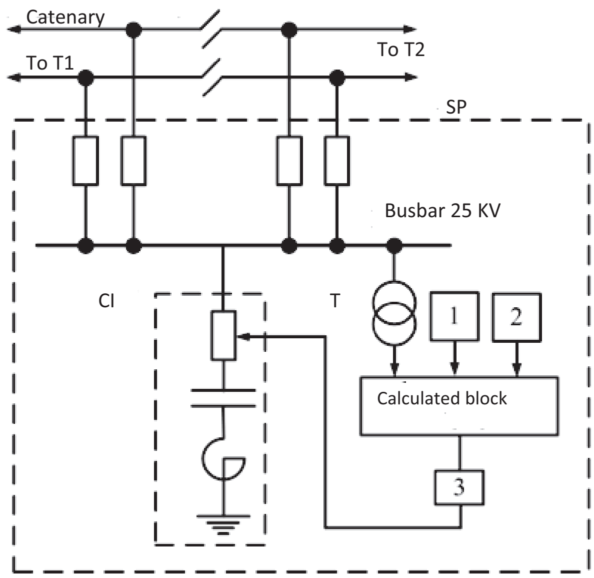
$\sum I_{pi} R_{ik} = \Delta U_{sp(k)} (\cos\phi) / a.$

It follows that the procedure for determining an optimal value of the current CI is based on measurements of voltage losses, which is expressed as algorithm.

CI is off

It is necessary to proceed with a set of steps, namely to:

1. Measure voltage on SP without CI U_{sp}.



Pic. 1. Schematic diagram of the installation.

2. Obtain information on telemechanics of voltage on busbars of 27,5 kV traction substations, supplying zone – U_o. If voltages are different, their average value is taken.

3. Determine ΔU_{ps} by the expression (3).

4. Calculate (6):

$\sum I_{pi} R_{ik}, = \Delta U_{nc} \cos\phi / a.$

5. Calculate I_k from (2) and (6):

$I_k = (\sum I_{pi} R_{ik}) / R_{kk} = \Delta U_{ps} \cos\phi / aR_{kk} =$
$= \Delta U_{ps} \cos\phi / Z_{kk(c)},$ (7)

where $Z_{kk(c)}) = Z' k_{(c)}$ is a composite resistance of connection node CI.

6. Calculate the power of CI, which would be optimal for the measured voltage loss (i. e. in this case power losses, when CI is on, would be the lowest (7)).

$Q_k = 27{,}5 I_k.$ (8)

7. If the resulting $Q_k \geq 0{,}5Q_{ko}$ (where Q_{ko} is power of CI), a command is given with a time delay for switching on CI.

CI is on

It is necessary to proceed with a set of steps, namely to:

1. Measure the voltage on SP with CI – $U_{sp(\kappa)}$.

2. Obtain information on telemechanics of voltage of busbars of 27,5 kV traction substations, feeding the zone. If voltages are different, their average value is taken.

3. Determine $\Delta U_{sp(\kappa)}$ by the expression (3a).

Table 1

Baseline data on the parameters of the scheme (Pic. 2)

Resistance BOO, Ohm
*Z*1 = 0,35+j 0,89 Resistance of double circuit HV line-110 kV
*Z*2 = 0,6+j 1,1
*Z*т = 0,1+j 1,886

4. Calculate the voltage loss, if CI has been switched off (i. e. excluding CI):

$\Delta U_{sp} = U_o - U_{sp(\kappa)} - I_k X_{kk}.$ (9)

5. Calculate the current CI by analogy with (7)

$I_k = (U_o - U_{sp(\kappa)} - I_k X_{kk}) \cos\phi / Z_{k(c)}.$ (10)

6. The current value of the appropriate power CI is defined by the formula (8).

7. If the resulting $Q_k \leq 0{,}5Q_{ko}$ (where Q_{ko} is power of CI), a command is given with a time delay for switching off CI.

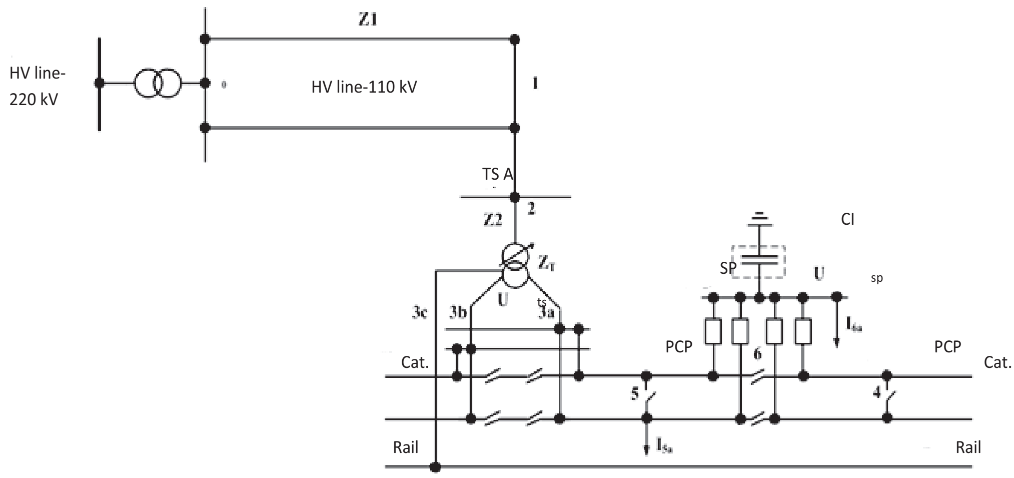
Computer experiment

According to the proposed algorithm calculations were conducted within software RAST-05K [3]. To simplify the calculations a section of traction network with single power supply was considered. In a circuit of double-track section section pillar with CI and parallel connection points (hereinafter- PCP) are in-

Table 2

Calculation results

№ of experiment	State of CI	Voltage drop to section pillar U, kV	Voltage losses to the section pillar U, kV	Voltage at the substation /section pillar (on the voltmeter), kV	The current value of appropriate power of CI calculated from the voltage drop / losses, Q_k	Control signal at CI
1	off	0,983+i 0,612	0,98	27,75 / 26,8	1,802/1,805	without control
2	off	3,276+i 2,039	3,27	24,8/21,98	3,106/3,099	switch on



Pic.2. The scheme of power supply of section A-III of 25 kV system.

stalled. Distributed traction load was equivalent in nodes 5 (PCP) and 6 (SP).

Resistance of traction network of between-substation zone Zts_1 = 2.775+j 7.2 Ohm.

Loads of 100 A (phase «–37˚») are concentrated at PCP and SP. We set voltage on TS A equal to 27,5 kV (all network parameters are reduced to voltage of 27,5 kV, so for traction winding we take a nominal transformation ratio K_T=1). We take nominal power of CI as 5,5 MVAr.

Further we assume (experiments 3 and 4) that the load on the section has changed to following values: PCP – 400 A, and SP – 300 A.

Given that the section pillar is located in the middle of considered section, we obtain for the composite resistance:

$Z_{ik(c)}=\cos\phi\ 2{,}775 + \sin\phi\ 7{,}2.$

We compare the resulting power of CI with 0,5 Q_{ko}=2,75 MVAr. The experimental data are summarized in Table 2.

As can be seen (Table 2), at low load CI remains in off-state, and at a higher load the installation should be switched on.

Relative error in the calculation of the voltage drop and losses is tenths of a percent. However, the main error of appropriate power of CI will be determined by accepted values of cosϕ (sinϕ).

On the main areas of railway traction load power factor varies within relatively narrow limits [1]. Therefore, we carry out calculations of error when changing the current phase from 29 ˚ to 45 ˚.

Then at traction load of 400 A for PCP and at 300 A for SP a current value of appropriate power of CI calculated on loss of voltage will vary from 3,757 to 2,548 MVAr, which amounts to error of up to 22%. The calculations were performed at high traction load when compensating current has less effect on power factor.

The obtained results indicate the acceptability of calculations on the proposed algorithm, since a considered error is several times smaller than for a similar calculation made by the regime of voltage on busbars of CI of section pillar. Computer experiment showed that the application of the algorithm improves the accuracy and therefore the effectiveness of power control of CI.

Conclusions.

1. An algorithm to control the installation of shunt capacitive compensation at section pillar of AC traction network of railway was proposed, allowing to increase the accuracy of control and adjustment. The algorithm provides for voltage information on busbars of traction substation and section pillar.

2. The example of calculation showed the acceptability of control using the developed algorithm.

Keywords: catenary, railway, traction energy, shunt compensation, section pillar, reactive power, voltage loss, algorithm.

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