Complex power control system for the installation of transverse capacitive compensation in the system with distributed load

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Abstract. The operation of transverse capacitive compensation installations (CI) when they are switched on away from the power source (for example, at partitioning posts in the traction network or in general-purpose networks, for example, at branch points from main networks) under distributed load has a number of features. These features are considered on the example of an electrified railway section. In particular, the problem of controlling the power of the CI at medium and maximum loads is analyzed. Power control schemes of the CI have been known for a long time, usually regulation is performed to minimize power losses in the supply network, to reduce the maximum reactive power of the consumer, to stabilize the voltage mode in the power system node, etc. For electrified sections, regulation is typical to reduce power losses in the traction network or to stabilize the voltage at the AC traction network partitioning post. However, with the growth of heavy traffic on the railways, the requirements for increasing the capacity of railway sections while reducing electricity losses in the traction network have increased, that is, there are requirements for an integrated control system for CI. The complexity of solving this problem is determined by the fact that the CI is located at the partitioning post. The article offers an algorithm for solving this problem using the harmonics of the electric rolling stock current.

1. Introduction

Operation of transverse capacitance compensation installations (CI) when they are switched on away from the power source (for example, at partitioning posts in the traction network or in General-purpose networks, for example, at points of branch from the main networks) it has a number of features. Let's look at these features on the example of an electrified railway section. In particular, we will analyze the well-known problem of controlling the power of the CI.

Until recently, specialists were guided by well-known regulatory documents when calculating the capacity of transverse capacitive compensation (CI) installations and developing principles for its regulation. However, it is known [1-6] that CI is a powerful technical means of increasing the capacity of railway sections. Therefore, it is no coincidence that a number of measures have recently been implemented for the CI to increase throughput.
Research goal is to develop methods and technical tools for a comprehensive power control system for installing transverse capacitive compensation in distributed load systems, which provides energy savings for small and medium loads and a set voltage value for large loads.

2. Materials and Methods

The control and automation of existing installations of transverse capacitive compensation (CI) are considered in [7-15]. And in [1] it is specified it is indicated that the third harmonic of the traction current is used to control the power of the CI of the partitioning post (PP). This is because the traction load measurements at the partitioning post do not reflect the actual load related to the PP. Indeed, if the same currents are located on both sides at the same distance from the PP, then the traction current attributed to (accounted for by) to the PP, is zero (no current flows through the PP), and the measured current of the PP supply line is zero. The power control CI occurs only for reducing power losses in the traction network, and does not take into account the main indicator of the mode - carrying capacity of the site.

To increase the capacity of the railway section, the voltage level in the traction network is increased, and therefore, the power of CI installations is currently being increased for this purpose. The most common CI installations on domestic railways are condenser installations that are switched on by a third - harmonic filter with sequential switching on of the main capacitor Bank and reactor to prevent resonant phenomena. An increase in the power of the CI is accompanied by an additional installation of the capacitor section, which allows to regulate the power of the CI, while the additional section can be switched on in parallel or in series with the main capacitor bank. Next, we will consider the inclusion of an additional section of the CI add in parallel with the main capacitor bank.

Thus, the main goal of the research carried out by the authors is to regulate the power of the CI in such a way as to increase the capacity of the electrified section of the railway.

We propose the following scheme for regulating the power of the CI (Fig.1), where the following designations are made:

1. Partitioning post (PP) with supply lines of the contact network on the switches;
2. PP tire;
3. Main switch of CI;
4. CI current transformer;
5. The reactor CI;
6. The main capacitor bank CI;
7. Additional capacitor bank CI add;
8. A switching device of the additional capacitor Bank CI add;
9. Unit additional capacitor Bank CI add with the switching apparatus;
10. The first resonant filter for the third harmonic in the secondary winding of the current transformer CI;
11. Relay for monitoring the third harmonic of the CU current;
12. Switch of the supply line PP;
13. The current transformer of the supply line PP;
14. The second resonant filter of the third harmonic in the secondary winding of the current transformer of the supply line;
15. The second band stop filter of the third harmonic in the secondary winding of the current transformer of the supply line;
16. Ammeter A(3) of the third harmonic of the supply line current;
17. Ammeter A(1) of the first harmonic of the supply line current;
18. The estimated unit;
19. Comparison unit \( I^{*}(1) > I \) installation;
20. Block for enabling an additional section CI add;
21. Block for disabling an additional section CI add;
22. The first barrier filter for the third harmonic in the secondary winding of the current transformer CI.
3. Results

Description of the operation and characteristics of blocks in the diagram.

Power of additional section CI, 9. Based on [1] power CI (Q1) of sectioning by the actual loads is usually equal to 4...5 MVAr and is determined by the need to reduce reactive power inter-station zone area to normalized values according to the formula "difference of tangents". In addition, [1] presents regulatory documents that require an increase in the power of the CI (up to Q2) to meet the requirement to ensure the voltage on the current collector of an electric rolling stock (ERS) of at least 21(24) kV. According to design experience, usually the implementation of [1] requires an increase in the power of the CI compared to the requirement (Q1) by 1.5 times. If the requirement to increase the throughput is met, it will be necessary to further increase the capacity of the CI (Q3). According to the design experience, the implementation of requires an increase in the power of the CI (Q3) in comparison with the variant (Q2) by another 1.5-2 times. Currently, the AC railway network has more than 200 such CIs, almost all of them require major repairs and corresponding modernization in terms of their terms and physical condition. Therefore, it is logical to pay attention at the present time to the modernization of existing CI taking into account the increase in the capacity of sections, which is considered in this article.

The total power of the CI together with the additional section of the CI_{add} is determined by
\[
Q^3 = (U_d - U_{\text{min}}) \frac{U_{\text{sgdm}}}{X_{\text{in}}},
\]

(1)

and then the power of the additional section of the CI, 9, is equal to

\[
Q_{CI_{\text{add}}} = Q^3 - Q^1,
\]

(2)

where: \(U_d\) – the desired voltage on the current collector, to increase the capacity of the section, depending on the nature of the load \(U_d = 25-28\) kV;

\(U_{\text{min}}\) – minimum voltage on the heavy-duty current collector according to the calculation;

\(U_{\text{sgdm}}\) – rated voltage of a static generator of reactive power of a static gas distribution mechanism (SGDM);

\(X_{\text{in}}\) – input inductive resistance of the sectioning post;

\(Q^1\) and \(Q^3\) of the CU capacity, respectively, according to the standard and the condition for increasing the capacity of the section [1].

On the necessity of forming filters of harmonic components of the traction current, 10,14,15. To get the current assigned to the PP, unfortunately, it is impossible to determine it from measurements. Indeed, at the same ERC currents on both sides and at the same distances from the PP, the PP current is zero. Under the current referred to the PP, we understand the current of the PP in this instantaneous scheme, obtained as a result of decomposition of the instantaneous currents of the inter-station zone network between traction substations and the PP. Therefore, to calculate the PP current, the third harmonic current \(I_{(3)}\) is used, which is characteristic of the rectifier electric rolling stock (ERS). No matter how placed ERS and as they were not all currents third harmonic of ERS are snapped via CI PP because the resistance of CI for the third harmonics of all the locomotives under review inter-station zone will be practically equal to zero. That is why a resonant filter for the third harmonic, 10, is connected to the current transformer of the CI PP, 4, with the third harmonic current monitoring relay, 11, in series in the CI PP. Note that the need to incorporate a band stop filter of the third harmonic is dictated by the observance of the mode of operation of the current transformer: as it always flows a current of the first harmonic, defined by the voltage on the PP tires, which excludes the no current in the secondary winding of the current transformer installation transverse capacitive compensation.

In CI PP will be to focus the whole current of the third harmonic of the traction network related to PP, and its maximum value will then define the current first harmonics of traction current, which should include an additional section CI.

However, to control the actual current first and third harmonics of the traction current should perform their measurements on a power line contact network (on any supply, such as switch 12 (Fig.1)).

The need to obtain currents of the first and third harmonics is dictated by determining the ratio of these currents in the traction network during normal operation of the inter-substation zone. The highest values of the first and third harmonic components prevail in the traction current. The current sensors of the third and first harmonics of current CI are formed on the secondary side of the current transformer 13 of the supply line for the circuit of the current transformer closes on resonant third harmonic filter 14 and band-stop filter of the third harmonic (to obtain the first harmonic current in the circuit of the filter 15), in a circuit which included the ammeter \(A_{(3)},17\), and \(A_{(1)},16\). For experimental determination of the coefficient \(\alpha (\alpha = A_{(3)}/A_{(1)}) \) a one-way power supply scheme should be performed at the time of measurement with the neighboring substation switched off (for increased values of traction currents and \(I_{*(3)}\), and excluding equalizing currents).

As a result of measurements, we get

\[
\alpha = A_{(3)}/A_{(1)}
\]

(3)

For calculations, we take the average value of \(\alpha\) from the measurements made. Using the coefficient \(\alpha (3)\), the current of the first harmonic is determined by the formula \(I^*_1\).
\[ I^*_1 = \frac{I^*_3}{\alpha}, \quad (4) \]

where \( I^*_3 \) is the maximum value of the measured third harmonic of the traction network current when the additional section is disabled \( \text{CI}_{\text{add}} \), and \( I^*_1 \) is the calculated value of the first harmonic of the traction current, at which the additional power of the \( \text{CI}_{\text{add}} \) is turned on, provided \( (5) \),

\[ I^*_1 \geq I_{\text{installation}}, \quad (5) \]

and when \( I^*_1 \geq I_{\text{installation}} \) is switched on, and when \( I^*_1 < I_{\text{installation}} \) the additional section \( \text{CI}_{\text{add}} \) is switched off. If it is necessary to control the capacitive component of the traction load, instead of \( I_1 \) and \( I_{\text{installation}} \), \( I_1 \sin \phi \) and \( I_{\text{installation}} \sin \phi \) are determined, where \( \sin \phi \) is determined by measurements in the section under consideration.

The estimated unit 18 determines:
- the third harmonic coefficient \( \alpha = A_3 / A_1 \) with the maximum value of \( A_3 \) and the disabled additional section of the CI using 16 and 17;
- the current of the first harmonic of the traction current, at which an additional section of the \( \text{CI}_{\text{add}} \) (4) and (5) is connected;
- set point current \( I_{\text{installation}} \) for switching to the capacity increase mode (see below (6)).

Thus, there are two modes of operation of the CI:
1) mode for reducing power losses in the traction network using the power control algorithm from [2].
2) with an increase in the current of the traction network assigned to the PP (5), you should switch to the second mode—the mode of increasing the capacity of the section.

We propose to pre-set the set point current to enable an additional section for the power of the \( Q_1 \) CI:

\[ I_{\text{installation}} = Q_1 / (27.5 \sin \phi) \quad (6) \]

Here, the introduction of \( \sin \phi \) in the denominator determines the setting for the full value of the traction current. For each real railway section, the preliminary \( I_{\text{installation}} \) value is specified based on the actual load of the section, the nature of train traffic, and the parameters of the power supply system. Further, according to the maximum current of the third harmonic in CI \( I^*_3 \), measured with disconnected additional section of the \( \text{CI}_{\text{add}} \) and the average value of the coefficient \( \alpha \) determines the current of the first harmonic of traction load \( I^*_1 \) and the execution (5) inclusion of additional sections \( \text{CI}_{\text{add}} \).

So, the novelty of the proposed technical solution is as follows:
1. The power control of the CI occurs not only to reduce power losses in the traction, but also to increase the capacity of the railway section, that is, a comprehensive power control is introduced.
2. The need for the introduction of power control to increase throughput is determined by the increased value of traction current, are related to PP, and when the traction current of the first harmonic more I include an additional section \( \text{CI}_{\text{add}} \).
3. The traction current of the first harmonic assigned to the PP is determined by measuring the third harmonic of the current in the CI and then calculated using the formula (4) with the measured harmonic coefficient \( \alpha \).

The third harmonic coefficient \( \alpha \) for calculating the first harmonic of the traction current is determined by forming the resonant and blocking filters of the third harmonic on the secondary winding of the current transformer of the supply line of the contact network of the PP.

4. Installation work.
When increasing the traction current assigned to the PP before setting \( I_{\text{installation}} \) and above, a command is given to turn on the additional section of the CI. As a result, the total power of the CI increases, therefore, the voltage in the traction network increases and the conditions for passing heavy
trains improve. As soon as the traction current decreases \( I \) \( I_\text{inst} \), which indicates a decrease in the traction load, the additional section of the CI\( \text{add} \) is switched off. The installation current for switching on the additional power of the CI\( \text{add} \) is determined by the expression (6).

Thus, a comprehensive system for regulating the power of the CI is implemented: before the traction current \( I_\text{(1)} \) \( I_\text{installation} \), the power of the CI is regulated to reduce power losses in the traction network, and during periods when the traction loads \( I_\text{(1)} \) \( \geq I_\text{installation} \), the power is regulated according to the law of increasing the capacity, that is, the AC is connected.

5. Conclusion
The idea of a comprehensive power control system for the CI should be implemented on all existing CI (first of all, on the PP), where the capacitor bank with the reactor is connected by a third-harmonic filter. However, the integrated power control system can also be used in other regulated CI, for example, in SGDM.

So, a comprehensive system of power control of the CU allows you to increase the capacity of the railway and reduce power losses.

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