Adaptive power supply system in plot with artificially complex profile

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Abstract. The paper deals with the issues of energy saving in the railway section, which has a tunnel with a double longitudinal slope, which limits the capacity of trains due to a decrease in the rated voltage by more than 10%, which negatively affects thermal and transient electromechanical processes. The practicality of voltage regulation using the existing installation of series compensation is shown; it is proposed to use an additional installation of parallel reactive power compensation, with automatic voltage regulation of the power transformer under load. The principle of self-tuning adaptive regulation is applied, establishing the optimal power supply mode according to the criterion of minimum losses, which has high reliability and cost indicators of traction power supply.

1 Introduction

With an increase in the volume of passenger and freight traffic, and a large length of the contact system, there are often irregularities in the feeder zone of the track, the presence of artificial structures in the form of long tunnels, there are often cases when traction asynchronous motors of electric trains due to a decrease in voltage and the presence of a longitudinal inclination of the track find themselves in conditions of limited bandwidth.

These conditions are characterized, first of all, by significant voltage drops, which lead to prolonged transportation. Here is brief technical information about the "Kamchik" tunnel built in 2016 on the "Angren-Pap" railway section of the Republic of Uzbekistan. This is a category III single-track railway from "Angren" to "Pap" with a maximum speed of 90 km/h. The total length of the tunnel is 19268.5 m, and its maximum depth is 1260 m. The tunnel has a double slope, that is, 20° length (11430 m) of the tunnel slope from west to east and 10.765° length (7770 m) of the descent.

The presence of a double slope of the tunnel reduces and increases the transition time of the electric rolling stock, leading to a decrease in voltage of 25 kV, exacerbating thermal transients and electromechanical processes.

Currently, the contact network is powered by the "Orzu" traction substation, which has a power transformer TDTNZh-40000/220/27.5/10. Its suction feeder is connected to a reactive power longitudinal compensation unit. Installation of parallel compensation of reactive compensation was not foreseen by the project. At present, these factors have led to
2 Methods
3 Results and discussions

Consider a mathematical model of electrical supply and supply of the required power with one traction substation "Orzu" with a power transformer equipped with automatic voltage regulation of the power transformer under load. We also consider the parameters of the adjustable installation of longitudinal capacitive compensation and the use of an additional device for transverse reactive power compensation to increase the capacity of the electric locomotive through a tunnel with a complex profile. For this, it is advisable to use the principle of adaptive voltage regulation [1, 2, 13] and limit the switching frequency of automatic voltage regulation of a power transformer under load to save its resource. For the operation of such a system, it is necessary to apply a calculated logic block (Fig. 1).

The basis of the calculated logic block of voltage regulation is a mathematical model that sets the following mode of allowable power according to the condition:

\[
\Delta P(\Delta U)_i \leq \Delta P_0,
\]

\[
U - U_{k_{\text{max}}} \leq 0,
\]

\[
U - U_{k_{\text{min}}} \geq 0.
\]

\[
\Delta S = \Delta S_{\text{TTP}} + \Delta S_{\text{TS}}
\]

\[
U_{k_{\text{min}}} \leq U \leq U_{k_{\text{max}}}
\]

\[
\Delta U = \Delta Z \cdot I
\]

\[
L_a = \frac{1}{3} (2L_b - L_b - L_c)
\]

\[
L_b = \frac{1}{3} (-L_a + 2L_b - L_c)
\]

\[
L_c = \frac{1}{3} (-L_a - L_b + 2L_c)
\]
and the matrix-column of currents of the traction transformer \( I \) is written as:

\[ I = C \cdot I_T \]

where \( I_T \) is the load current matrix of the power transformer.

The power loss in the power transformer is written as:

\[ \Delta S_T \rho = (C I^*_T \cdot Z_\delta \cdot C (I^*_T)) \cdot Z \Delta \cdot C (I^*_T) \]

where \( (I^*_T) \cdot Z \Delta \cdot (I^*_T) \) is transposed sum of conjugated column matrices 3N currents of a three-phase transformer; Incident matrix for connecting a single-phase traction network to a three-phase power transformer.

Taking into account the rules of operations on matrices, we can rewrite expression (7) in the form:

\[ \Delta S_T \rho = (I^*_T) \cdot Z \cdot C \cdot (I^*_T) \]

Power losses in the traction network from the traction load \( \Delta S_t \) are determined by the method given in [3].

Taking into account (3)÷(7) and matrices of nodal own \( Z_{ii} \) and mutual resistances \( Z_{ij} \), the total power losses of the traction power supply system are written in matrix form:

\[ \Delta S_c = (I^*_T) \cdot Z_{oy} \cdot (I_T) + \Delta S_t \]

where \( Z_{oy} \) is a 3N*3N matrix of resistances of the contact network connected through a feeder to a power transformer; \( Z_{oy} \) is matrix of reduced resistances corresponding to the changeable transformation ratio; \( k_\Delta \) is diagonal matrix of relative transformer coefficients.

Formula (8) shows that the first two components of power losses in the external power supply system and in the contact network depend on the power transformation coefficient \( k_\Delta \) and the changing parameters of the longitudinal-transverse compensation installation.

Note that the power consumption in the contact network depends on electric locomotives' established mode of movement.

The above formulas can be considered as a mathematical model when the voltage changes to assess the active losses in the contact system \( \Delta S_c \). To calculate active power losses, which is a real component of the total power of the system under consideration, we can write [11]:

\[ \Delta P_c = Re(\Delta S_c) = (I^*_T) \cdot R_{oy} \cdot (I_T) + \Delta S_t \]

\[ P = \frac{\Delta (I^*_T) \cdot k^\delta \cdot (I_T) \cdot R_{oy}}{\Delta k^\delta} + \frac{\Delta (I^*_T) \cdot R_{oy}(I_T)}{\Delta k^\delta} + R_{oy}k^\delta \cdot (I_T) + \]

\[ + \frac{\epsilon (I^*_T \cdot R)(I_T)}{\Delta k^\delta} - 2 \cdot \frac{(I_T)k^\delta \cdot (I_T)}{\Delta k^\delta} \cdot R_{oy}k^\delta \cdot (I_T) + 2 \cdot \frac{(I^*_T) \cdot R}{\Delta k^\delta} \cdot R_{oy}\cdot (I_T) \]
\[ P = \frac{\Delta P_e}{\Delta k} = 2 \times \left( l_T^2 + MZ_{kon}^T \times (2k^2 \overline{E} + 6k^2 Z_{DY}k^2 I_T - Z_{DY}I_T) \right) \times R_{ov}k^2 \times \left( l_T + MZ_{kon}^T \times (k^2 \overline{E} - k' \overline{E}Z_{DY}k' I_T - Z_{DY2}I_T) \right) + \left[ 2 \left( MZ_{kon}^T \times (E^2 - 2Z_{DY}k^2) \right) \times R_{ov}k^2 \times \left( l_T + MZ_{kon}^T \times (k^2 \overline{E} - k' \overline{E}Z_{DY2}k' I_T - Z_{DY2}I_T) \right) + \left[ 2 \times \left( Z_{kon}^T \times (k^2 \overline{E} - k' \overline{E}Z_{DY}k' I_T - Z_{DY2}I_T) \right) \right. \]

\[ \Delta P_e = \frac{\Delta l_T}{\Delta k} \times R_{ov}k^2 \times \left( l_T + MZ_{kon}^T \times (k^2 \overline{E} - k' \overline{E}Z_{DY}k' I_T - Z_{DY2}I_T) \right) \]

\[ X_k = \frac{U_k}{I_k} \]

\[ X_p = X_{x} + X_{ts}, X_{yn}, X_{ts} \]

\[ U_{tk} = U_t + I_k \text{CM}(x_p + Lx_{ts}) \]

\[ \Delta S_{TP}, \Delta S_{TS}, \Delta S_{TP}, \Delta S_{CT} \]

4 Conclusions
References


