Identifying the factors influencing the voltage quality of 6kV grids when using electric excavators in surface mining

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Abstract  
Purpose. The research purpose is to study the relationship between the number of electric excavators and their impact on reducing the voltage losses. As a result of the research, it becomes possible to obtain factors that can help the manager to correctly understand the effect of power compensation caused by the over-excitation mode of electric excavators.  
Methods. The paper uses the Jacobian matrix transformation to simulate the power flows of electric excavators, the driving mechanisms of which are mainly synchronous motors. The input data for the simulation is the in-situ measurement data representing the inverse power flow. A diagram and a software to determine the factors corresponding to the number of electric excavators are also provided.  
Findings. A cross-reference table has been compiled showing the ratio of factors corresponding to the number of electric excavators in a 6kV grid. An appropriate software has also been developed, including a table for correcting typical equations for calculating voltage losses.  
Originality. The proposed factor is conditioned by over-excitation mode of excavators operating as compensation machines in a 6kV grid.  
Practical implications. When calculating the voltage loss in a 6kV grid of surface mines, if the design feeder contains electric excavators, a modified factor should be added to give a correct idea of the voltage quality.  
Keywords: electric excavator, voltage quality, over-excitation mode, Jacobian matrix transformation, open-pit mining

1. Introduction  
In the 6kV grids of Vietnam surface coal mines, power quality (PQ) problems are not new, but only recently the consequences of these problems have gained public attention, as well as much attention from operators. Due to an increase in the output capacity, the number of electric excavators is increasing rapidly. The use of these high capacity loads in mining practice also causes the PQ violations as well as voltage quality violations. Many studies have shown that in surface mines, electric excavators (EEx) with high capacity loads can significantly affect the voltage quality. However, none of them are mentioned by number, and the total apparent power of EEx in some typical surface mines in Vietnam is given in Table 1 [1], [2].

![Table 1. Number and total apparent power of EExs in typical surface coal mines](image)

As can be seen from Table 1, the number of EEx in surface coal mines of Vietnam has grown rapidly because, according to the estimated data presented in the energy consumption report, these devices consume from 40\% to 65\% of the total electrical energy of coal mining companies [1]. In electrical energy diagram (6kV grids), all electric excavators are powered by a single feeder with a few PCC nodes (skeleton diagram). The improper connection of such high capacity loads in a 6kV grid can lead to temporary overload. Therefore, it is necessary to take into account the operating mode of excavators when analyzing voltage quality.

At present, most of the excavators in Vietnam’s surface mines are electric ones, which are equipped with synchronous motors as the main driving mechanism [3]-[5]. During a cycle of digging operations, these types of motors may have a reverse power during lowering or slewing stoppage [6]. Table 2 shows the specification of driving motors on EEx.

<table>
<thead>
<tr>
<th>Year</th>
<th>Cao Son</th>
<th>Coc Sau</th>
<th>DeoNai</th>
<th>NuiBao</th>
</tr>
</thead>
<tbody>
<tr>
<td>2017</td>
<td>16</td>
<td>8246</td>
<td>18</td>
<td>5814</td>
</tr>
<tr>
<td>2018</td>
<td>18</td>
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<td>5814</td>
</tr>
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<td>2019</td>
<td>17</td>
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<td>5814</td>
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<td>2020</td>
<td>18</td>
<td>8725</td>
<td>20</td>
<td>6563</td>
</tr>
</tbody>
</table>

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It could be seen that the 6kV synchronous motor (SyM) on EEx is the main energy consumer that is responsible mainly for digging in cycles.

Many studies [7]-[12] showed the dynamic performance as well as the energy consumption by EEx. All 4 main parts of EEx are examined to show a general moving as well as all positions of bucket, stick, boom cylinders, and angles of swing system (Fig. 1).
Table 2. Specification of driving motors on EEx

<table>
<thead>
<tr>
<th>Name</th>
<th>Type of driving system</th>
<th>$U_{nom}$ (kV)</th>
<th>$P_{nom}$ (kW)</th>
<th>$\cos \phi$</th>
</tr>
</thead>
<tbody>
<tr>
<td>EKG 4.6 A and 5A</td>
<td>3 phase SyM</td>
<td>6</td>
<td>250</td>
<td>0.86</td>
</tr>
<tr>
<td></td>
<td>Air pressure motor</td>
<td>0.22</td>
<td>15</td>
<td>0.85</td>
</tr>
<tr>
<td></td>
<td>Cooling Fan motor</td>
<td>0.22</td>
<td>2.2</td>
<td>0.85</td>
</tr>
<tr>
<td></td>
<td>Cooling Fan motor</td>
<td>0.22</td>
<td>1.5</td>
<td>0.85</td>
</tr>
<tr>
<td></td>
<td>Oil pumping motor</td>
<td>0.22</td>
<td>1.5</td>
<td>0.85</td>
</tr>
<tr>
<td>EKG8Y</td>
<td>Motor of auxiliary</td>
<td>0.38</td>
<td>40</td>
<td>0.85</td>
</tr>
<tr>
<td></td>
<td>Air pressure motor</td>
<td>0.38</td>
<td>15</td>
<td>0.85</td>
</tr>
<tr>
<td></td>
<td>Cooling Fan motor</td>
<td>0.38</td>
<td>2.2</td>
<td>0.85</td>
</tr>
<tr>
<td></td>
<td>Cabin Ceiling fan motor</td>
<td>0.38</td>
<td>3</td>
<td>0.85</td>
</tr>
<tr>
<td>EKG10A</td>
<td>3 phase SyM</td>
<td>6</td>
<td>750</td>
<td>0.89</td>
</tr>
<tr>
<td></td>
<td>Motor of auxiliary</td>
<td>0.38</td>
<td>40</td>
<td>0.85</td>
</tr>
<tr>
<td></td>
<td>Air pressure motor</td>
<td>0.38</td>
<td>15</td>
<td>0.85</td>
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<tr>
<td></td>
<td>Cooling Fan motor</td>
<td>0.38</td>
<td>2.2</td>
<td>0.85</td>
</tr>
<tr>
<td></td>
<td>Cabin Ceiling fan motor</td>
<td>0.38</td>
<td>3</td>
<td>0.85</td>
</tr>
</tbody>
</table>

The kinematics and dynamics of excavators are also calculated [9], [10], [12]. However, the calculation results show that the EEx digging operations (lowering or slewing procedure) contain negative power flows and negative electromagnetic torque (Figs. 4 and 5). During these time intervals, EEx act as a power source that supplies power to the 6kV grid rather than load.

These specific working characteristics of the EEx driving system are indicated in many studies [8]-[10], [14]-[16]. These studies indicate that the energy saving level of EEx is great due to the recovery of the potential energy or a kinetic energy during lowering or slewing stoppage. This is mainly caused by the digging process, which significantly influences on the mechanic and kinetic parameters of the EEx itself.

The energy saving efficiency of EExs is determined in the range from 20 to 30%, taking into account the individual consideration of each excavator [15], [17], [18].

It is obvious that when operating EEx as power sources, the voltage quality of the feeders to which they are connected can be improved. Their electrical energy can power loads around PCC (point of couple connection) nodes. The next section of this paper gives the analysis of this special operating mode to reduce the voltage drop.

2. Simulation of the energy recovery of excavators

To estimate the impact of special working mode of EExs, the following steps are implemented. Each EEx must be simulated on Matlab to understand about their reverse power consumption. The energy consumption of the excavator during the boom operation [9].

Figure 1. Working cycle diagram for bucket, stick, boom cylinders and swing system

Based on the working cycle analysis, many dynamic models have been built to get driving moments of the components and energy consumption during the boom operation (Figs. 2 and 3).

Figure 2. Driving forces/moment diagram for bucket, stick, boom cylinder and swing system

Figure 3. Energy consumption of the excavator during the boom operation [9]

Figure 4. Simulation results of a mining shovels cycle with a bucket capacity of 5.0 m³ (PU) [13]

Figure 5. Electromagnetic torque of hoist bucket mechanism electric drive: 1 – for the $\alpha$-$\beta$ coordinate system arbitrary orientation, N·m; 2 – for the $\alpha$-$\beta$ coordinate system orientation of the rotor flux vector, N·m; 3 – $\omega_r$ (angular frequency of the rotor rotation), RPM×10 [13]
flows at the moment of lowering or slewing stoppage. The onsite measurements are implemented individually with each excavator to verify the precise of simulation model.

In final stage, each energy consumption of a single feeder with connected electric excavators is measured. The results are compared with theoretical computation to deduct the modifying/correction factors that obtain the decrease level corresponding to the number of electric excavators. To assist the calculation process, a software is established with application of Jacobian matrix transformation.

2.1. Simulation the operation of synchronous motor on excavator

To describe the flux ratio in a synchronous motor, a matrix equation is shown in 1 [19], [20]. Theoretically, flux reaction on the synchronous motor rotor is presented in the form of space-vector equations (Eq. 2) [21].

\[
\begin{bmatrix}
U_{as} \\
U_{bs} \\
U_{cs} \\
U'_{ar} \\
U'_{br} \\
U'_{cr}
\end{bmatrix}
= \begin{bmatrix}
r_s & 0 & 0 & 0 & 0 & 0 \\
0 & r_s & 0 & 0 & 0 & 0 \\
0 & 0 & r_s & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & r_s & 0 \\
0 & 0 & 0 & 0 & 0 & r_s \\
0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}
\begin{bmatrix}
i_{as} \\
i_{bs} \\
i_{cs} \\
i_{ar} \\
i_{br} \\
i_{cr}
\end{bmatrix}
+ \frac{d}{dt} \begin{bmatrix}
\lambda_{as} \\
\lambda_{bs} \\
\lambda_{cs} \\
\lambda_{ar} \\
\lambda_{br} \\
\lambda_{cr}
\end{bmatrix};
\]

(1)

The accelerating torque equation:

\[
T_{acc} = T_{em} + T_{mech} - T_{damp} = J \frac{d\omega(t)}{dt} = \frac{2J}{P} \cdot \frac{d[\omega(t) - w_e]}{dt},
\]

(4)

where:

\[
T_{em} = \frac{3}{2} \left( \frac{P}{2} \left( L_q - L_d \right) i_d \cdot i_q + \frac{3}{2} \right) \times \frac{P}{2} \left( L_{md} \cdot i_{qd} \cdot i_d - L_{md} \cdot i_{dq} \cdot i_d \right) + \frac{3}{2} \frac{P}{2} L_{md} \cdot i_m \cdot i_q.
\]

(5)
The equation of active and reactive power delivered by motor:

\[
|V_l| = \sqrt{V_{q*}^2 + V_{d*}^2};
\]

\[
|V_l| = \sqrt{I_{q*}^2 + I_{d*}^2};
\]

\[
P = R_m \left[ (v_q - jv_d) \left( i_q - ji_d \right) \right]^* = v_q i_q^* + v_d i_d^*;
\]

\[
Q = I_m \left[ (v_q - jv_d) \left( i_q - ji_d \right) \right]^* = v_q i_d^* + v_d i_q^*.
\]  

(6)

The results obtained from the simulation of electric excavators are shown in Figures 7 and 8 (implemented with motors at the Cao Son and Coc Sau open-pit coal mines of Vietnam).

In Figures 7 and 8, there are time intervals showing the power below the zero line. This means that at these moments the excavators do not deliver power from the source, but they operate as a source for supplying energy to the grid. Therefore, they play the role of improving the power quality in the grid.

![Simulation of driving system on a synchronous motor of an electric excavator](Image)

**Figure 6. Simulation of driving system on a synchronous motor of an electric excavator**

![Three-phase active power of EKG8A, simulated on PCC node of the Cao Son open-pit coal mine](Image)

**Figure 7. Three-phase active power of EKG8A, simulated on PCC node of the Cao Son open-pit coal mine**

### 2.2. On-site verification of special operating mode of excavators

The illustration from the above simulation is verified by on-site measurements. Using real-time meters, the results of the active power consumed by electric excavator are shown in Table 3. Other representation of this power is shown in Figures 9 and 10.

![Three-phase active power of EKG8A, simulated on PCC node of the Cao Son open-pit coal mine](Image)

**Table 3. On-site measurement at the Cao Son and Coc Sau open-pit coal mines in Vietnam**

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Elapsed time</th>
<th>P_{tot}, W</th>
<th>P_{init}, W</th>
<th>P_{2init}, W</th>
</tr>
</thead>
<tbody>
<tr>
<td>9/20/2019</td>
<td>15:18:23</td>
<td>00:00:17</td>
<td>22.260</td>
<td>17.740</td>
<td>0</td>
</tr>
<tr>
<td>9/20/2019</td>
<td>15:18:24</td>
<td>00:00:18</td>
<td>54.540</td>
<td>34.520</td>
<td>23.010</td>
</tr>
<tr>
<td>9/20/2019</td>
<td>15:18:25</td>
<td>00:00:19</td>
<td>181.200</td>
<td>98.680</td>
<td>84.530</td>
</tr>
<tr>
<td>9/20/2019</td>
<td>15:18:26</td>
<td>00:00:20</td>
<td>117.700</td>
<td>63.160</td>
<td>47.520</td>
</tr>
<tr>
<td>9/20/2019</td>
<td>15:18:27</td>
<td>00:00:21</td>
<td>111.300</td>
<td>57.650</td>
<td>42.540</td>
</tr>
<tr>
<td>9/20/2019</td>
<td>15:18:28</td>
<td>00:00:22</td>
<td>236.200</td>
<td>124.900</td>
<td>112.100</td>
</tr>
<tr>
<td>9/20/2019</td>
<td>15:18:29</td>
<td>00:00:23</td>
<td>537.600</td>
<td>255.100</td>
<td>257.800</td>
</tr>
<tr>
<td>9/20/2019</td>
<td>15:18:30</td>
<td>00:00:24</td>
<td>416.800</td>
<td>214.300</td>
<td>196.400</td>
</tr>
<tr>
<td>9/20/2019</td>
<td>15:18:31</td>
<td>00:00:25</td>
<td>228.600</td>
<td>121.000</td>
<td>108.600</td>
</tr>
<tr>
<td>9/20/2019</td>
<td>15:18:32</td>
<td>00:00:26</td>
<td>182.800</td>
<td>98.740</td>
<td>83.070</td>
</tr>
<tr>
<td>9/20/2019</td>
<td>15:18:45</td>
<td>00:00:39</td>
<td>155.500</td>
<td>84.810</td>
<td>71.560</td>
</tr>
<tr>
<td>9/20/2019</td>
<td>15:18:46</td>
<td>00:00:40</td>
<td>221.200</td>
<td>109.200</td>
<td>91.220</td>
</tr>
<tr>
<td>9/20/2019</td>
<td>15:18:47</td>
<td>00:00:41</td>
<td>-176.200</td>
<td>-82.760</td>
<td>-113.300</td>
</tr>
<tr>
<td>9/20/2019</td>
<td>15:18:48</td>
<td>00:00:42</td>
<td>-125.000</td>
<td>-51.730</td>
<td>-66.250</td>
</tr>
<tr>
<td>9/20/2019</td>
<td>15:18:49</td>
<td>00:00:43</td>
<td>66.040</td>
<td>36.500</td>
<td>27.540</td>
</tr>
<tr>
<td>9/20/2019</td>
<td>15:18:50</td>
<td>00:00:44</td>
<td>68.130</td>
<td>41.490</td>
<td>28.530</td>
</tr>
<tr>
<td>9/20/2019</td>
<td>15:18:51</td>
<td>00:00:45</td>
<td>82.530</td>
<td>48.380</td>
<td>35.040</td>
</tr>
<tr>
<td>9/20/2019</td>
<td>15:18:52</td>
<td>00:00:46</td>
<td>83.930</td>
<td>47.380</td>
<td>36.550</td>
</tr>
<tr>
<td>9/20/2019</td>
<td>15:18:53</td>
<td>00:00:47</td>
<td>87.950</td>
<td>51.480</td>
<td>39.570</td>
</tr>
</tbody>
</table>

Figures 9 and 10 present the three-phase active power, as well as the total \( P_{\text{tot}} \) delivered by the excavators. As in Table 3, there are also periods of time when the “\( P \)” value is below the zero line.
Figure 9. Three-phase active power of EKG8A, simulated on PCC node of the Cao Son open-pit coal mine

Figure 10. Three-phase active power of EKG8A, simulated on PCC node of the Cao Son open-pit coal mine

This effect is called “regenerating braking operation”. The figures once again prove the confirmation of delivered power of EEx as an individual source. Therefore, when there are more EEx on the feeder, their impact on the voltage quality improvement is significant and should be determined.

3. Determining the correction factors and analyzing its impact on voltage estimation

3.1. Determining the correction factors

There are not many studies devoted to the reverse power flows of EEx. But their impact on saving energy is mainly shown by Equation 7 [17],

$$\sum F_{\text{generate}} = \int_{t_0}^{t_{\text{finish}}} R_{\text{breaking}} (I_{\text{generated}})^2 dt,$$

(7)

where:

- $R_{\text{breaking}}$ – the breaking resistor;
- $I_{\text{generated}}$ – the generated current.

Based mainly on the energy consumed by the feeder containing EEx, this energy is calculated using a classical formula and compared with on-site measurement result at the PCC feeder nodes. Two typical feeders are presented in Figures 11 and 12.

Table 4. Comparison of energy consumption calculation results with on-site energy measurements at surface coal mines in Vietnam

<table>
<thead>
<tr>
<th>Number of excavators</th>
<th>$A_1$ (kWh) calculated by theoretical formulas</th>
<th>$A_2$ (kWh) on-site measurement at PCC nodes of feeders</th>
<th>Ratio $A_2/A_1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>586233</td>
<td>551060</td>
<td>0.939</td>
</tr>
<tr>
<td>2</td>
<td>837992</td>
<td>762612</td>
<td>0.91</td>
</tr>
<tr>
<td>3</td>
<td>1411647</td>
<td>1224462</td>
<td>0.8674</td>
</tr>
<tr>
<td>4</td>
<td>1292532</td>
<td>1057292</td>
<td>0.818</td>
</tr>
<tr>
<td>1</td>
<td>1289303</td>
<td>1206788</td>
<td>0.936</td>
</tr>
<tr>
<td>2</td>
<td>2005337.7</td>
<td>1830873.3</td>
<td>0.913</td>
</tr>
<tr>
<td>3</td>
<td>2810630</td>
<td>2436816</td>
<td>0.867</td>
</tr>
<tr>
<td>4</td>
<td>3525644</td>
<td>2884329</td>
<td>0.818</td>
</tr>
<tr>
<td>1</td>
<td>1466554</td>
<td>1381494</td>
<td>0.941</td>
</tr>
<tr>
<td>2</td>
<td>2770909</td>
<td>2061985</td>
<td>0.908</td>
</tr>
<tr>
<td>3</td>
<td>3692430</td>
<td>3200229</td>
<td>0.871</td>
</tr>
<tr>
<td>4</td>
<td>3922495</td>
<td>3207424</td>
<td>0.877</td>
</tr>
</tbody>
</table>

Table 5. A series of modifying factors corresponding to EEx numbers at surface coal mines in Vietnam

<table>
<thead>
<tr>
<th>Number of EExs</th>
<th>Value of factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.94</td>
</tr>
<tr>
<td>2</td>
<td>0.91</td>
</tr>
<tr>
<td>3</td>
<td>0.87</td>
</tr>
<tr>
<td>4</td>
<td>0.82</td>
</tr>
<tr>
<td>5</td>
<td>0.74</td>
</tr>
<tr>
<td>6</td>
<td>0.69</td>
</tr>
<tr>
<td>7</td>
<td>0.65</td>
</tr>
</tbody>
</table>

It can be seen from Table 5 which EEx number has a great impact on the power consumption of the feeder supplying power to the excavator, the ratio can be 35%. Obviously, the voltage calculation in these feeders should be estimated proportionally. The next section of this paper studies the significance of the correction factor impact.

3.2. Analyzing the impact of correction factors on voltage calculation in feeders of 6kV grids in surface mines

To analyze the impact of factors, a software is developed, which is based on Jacobian matrix transformation [22], [23]. To perform correctly voltage calculation of 6kV grid, the following assumption must be taken into account:

- shunt admittances of transmission lines can be omitted;
- all buses in the grid are load buses.
With this assumption, based on the power flow Equation presented in 8 and 9, the block diagram is shown in Figure 13. Figure 13 shows a diagram expressing the use of modifying factors obtained from the reactive power delivered by electric-excavators. With account of these series of factors, the typical formula to verify voltage drop in a medium voltage (MV) grid has been significantly modified. Due to reactive-power compensation caused by electric excavators, all voltage drops must be multiples with a factor less than 1. In some cases, the results are greatly modified (lowered) by more than 30%. Hence, most managers and technicians responsible for the operation of MV grids must take this factor into account, which can lead to a correct understanding of the technical situation of MV grid. Moreover, the influence of these series values has a positive effect, since it shows the impact of reducing power flows transmitted in the conductor. The greater the number of excavators connected in the feeder, the greater the modifying factor (Table 5).

The power differences on 6kV feeders and buses expressed in Equations 8 and 9. The mismatch of buses in the form of Equations 8 and 9 are collected into a vector-matrix equation and expressed in Formula 10.

\[
\Delta U_k = \frac{\partial P}{\partial U_2} \Delta U_2 + \frac{\partial Q}{\partial U_2} \Delta U_2 + [U_2] \frac{\partial P}{\partial U_2} U_2 + [U_2] \frac{\partial Q}{\partial U_2} U_2
\]

\[
\Delta Q_k = \frac{\partial Q}{\partial U_2} \Delta U_2 + \frac{\partial Q}{\partial U_2} \Delta U_2 + [U_2] \frac{\partial Q}{\partial U_2} U_2 + [U_2] \frac{\partial Q}{\partial U_2} U_2
\]

For obtaining the impact of EEs on the voltage estimation, the factor k is included in the calculation of the Equation 11:

\[
\Delta \delta U = \frac{U_i - U_{nom}}{U_{nom}} \cdot 100\% \cdot k
\]

where:

- \(U_i\) – voltage amplitude at bus \(i\);
- \(U_{nom}\) – rated voltage of grid.

Using a series of factors from Table 5 or software implementation, the voltage deviation calculation with and without these factors is presented in Table 6.

### Table 6. Verifying the results of voltage deviation with and without taking into account the impact of using the excavators

<table>
<thead>
<tr>
<th>Name</th>
<th>Feeder No</th>
<th>No of EEs</th>
<th>(\Delta U) without k</th>
<th>(\Delta U) with k, V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cao Son</td>
<td>4</td>
<td>5</td>
<td>501.7</td>
<td>0.74</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>556.76</td>
<td>1.00</td>
</tr>
<tr>
<td>Coc Sau</td>
<td>2</td>
<td>6</td>
<td>669.6</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>502.23</td>
<td>0.94</td>
</tr>
<tr>
<td>Deo Nai</td>
<td>6</td>
<td>3</td>
<td>526.1</td>
<td>0.87</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>715.56</td>
<td>0.87</td>
</tr>
</tbody>
</table>

It can be seen from the table that if the operator in surface mines ignores the good impact of electric excavator, there is some voltage quality violation in the feeders to which EEs is connected (feeder No 4 in Cao Son; No 2, 10 in Coc Sau; No 6 in Deo Nai). The violated voltage deviation value is 480V (permmissible limit – 5% \(U_{nom}\)). If factors are used for correction, the true values of \(\Delta U\) are improved, most of which are below 480V. This means that there are no technical solutions to improve voltage quality on these feeders.

**Figure 13. Block diagram presenting the calculation of the voltage drop in a 6kV grid, taken into account the EEs impact**
4. Conclusions

By comparing simulation in MATLAB and on-site measurements, an in-depth study of the operation of electric excavators has been performed. Some facts should be taken into account following the impact of these machines on the operation of MV grids.

When working on-site, all electric excavators have a reverse power flow due to the presence of a synchronous driving motor. These power flows act as power source compensation, which reduce significantly the voltage drop in 6kV feeders in surface mines.

By re-comparing the results of theoretical calculation and on-site measurements, a series of modifying factors corresponding to the typical number of 6kV electric excavators have been determined. Depending on the number of electric excavators used in the feeder, a good impact on the field of the voltage deviation improvement has been substantiated.

The impact of using the excavators in surface-mining grids cannot be ignored. These values must be used for statistical estimation of voltage on 6kV feeders in surface mines, since the level of their impact is very high (nearly 35%) on theoretical calculations. A correct understanding of excavators as a compensating power source helps mine operators to better analyze the voltage drop calculation.

The energy saving level of the excavator, implemented in the paper, is more specific than the wide range (20% to 30%) indicated in previous studies [17], [18], [24].

Due to the fact that there are many types of various capacities used in surface mine grids in Vietnam, another detailed analysis is needed to determine the level of impact of each type or each series of capacities. Moreover, since excavators significantly reduce voltage drop, the technical voltage testing procedure needs to be improved to reflect a true understanding of grids. For this purpose, a computer program based on the diagram in Figure 13 is a good recommendation.

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References


Выводы факторов, которые влияют на якість напруги в мережах 6 кВ, при використанні електричних екскаваторів на відкритих гірничих роботах

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Мета: Вивчення залежностей між кількістю електроекскаваторів та їх впливом на зниження втрат напруги для встановлення факто- рів, які допоможуть менеджеру правильно зрозуміти ефект компенсації потужності, спричинений режимом передбачення електри- чних екскаваторів.
Методика. У статті використано перетворення матриці Якобі для моделювання потоків потужності електроекскаваторів, механізмами приводу яких є переважно синхронні двигуни. Вхідними даними для моделювання є дані вимірювання на місці, що представляють зворотний потік потужності. Також надається схема та програмне забезпечення для визначення факторів, що відповідають кількості електричних екскаваторів.

Результати. Визначено ряд модифікуючих факторів, що відповідають типовій кількості електричних екскаваторів 6 кВ шляхом повторного порівняння результатів теоретичних розрахунків та вимірювань на місці. Обґрунтовано позитивний вплив на поле покращення напруги залежно від кількості електричних екскаваторів, що використовуються у живильнику. Складено таблицю перехресних довідок, яка показує співвідношення факторів, що відповідають кількості електроекскаваторів мережі 6 кВ. Розроблено також відповідне програмне забезпечення, що включає таблицю для корекції типових рівнянь для розрахунку втрат напруги.

Наукова новизна. Встановлено, що запропонований фактор обумовлений режимом перезбудження екскаваторів, що працюють як компенсаційні машини в мережі 6 кВ.

Практична значимість. Результати є корисними при розрахунку втрат напруги у мережі 6 кВ при відкритих гірничих роботах і якщо проектний живильник містить електричні екскаватори, то слід додати модифікований коефіцієнт, щоб дати правильне уявлення про якість напруги.

Ключові слова: електричний екскаватор, якість напруги, режим перезбудження, перетворення матриці Якобі, відкриті гірничі роботи