RESEARCH ON BUILDING FOR DEPENDENCE OF INSULATION PARAMETERS OF THE 6kV GRID WITH THE ENVIRONMENT AND STRUCTURAL PARAMETERS OF OPEN-PIT MINES IN THE QUANG NINH AREA

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Abstract:
Medium voltage insulation indicators depend on many factors such as environment, length of feeders, numbers of transformers and motors connected on the grid. The values determined by experimental measurements will be used to build up maths distributions. Base on these results, an experimental equation will be formed for determining capacitance and impedance of 6kV grid to ground in Quang Ninh open pit coalmines.

Keywords: A One-Phase Earth Fault; An Insulated-Neutral Grid; An Insulation Parameter; A Sensitive Earth Fault Relay.

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1. Introduction

Building a 6kV grid model of open-pit mines in the Quang Ninh area, used to investigate the transient process in switching of short-circuit switches in fault phases so as to ensure safety when there occur single-phase earth faults, need take into account the effect of insulation resistance, the capacitance, loads, compensate capacitors and potential transformers.

The insulation resistance and capacitance of the 6kV open-pit mine grid in the Quang Ninh area depend on the operating environment such as temperature, humidity,... and the structural parameters of the grid. Based on the measured data, it is possible to determine the dependence of the environment and the open-pit mine 6kV grid’s structure such as: the supply line length, the number of low-voltage transformers, the number of high-voltage motors. Therefore, this results are the basic factors for the grid modeling.
2. Research On Selection Of Measuring Methods To Identify Insulation Parameters Of Open-Pit 6kv Mine Grids In The Quang Ninh Area

2.1. Elementary Theory

Research on the analysis and comparision of measurable methods enable to choose a three- volt meters method for determination the capacitance (C) and the conductance(G) of the grid to the ground. This method has the outstanding advantage, such as no creation artificial short-circuit causing insecurity, in complex measurable techniques and instruments. Although calculations are complex, it is extremely convenient to program by a computer. The principle diagram is shown in Figure 1[1,4].

Figure 1: The diagram illustrates determination of the capacitance (C) and the conductance (G) of the grid to the ground by the 3-volt meters method

\[ \mathbf{U}_A, \mathbf{U}_B, \mathbf{U}_C \] - the complex number of voltage of phase to ground;
\[ R_A, R_B, R_C, C_A, C_B, C_C \] – the resistance and capacitance of phase to ground;
\[ C_{ph} \] – the auxiliary capacitance;
\[ MC_1 \] – the circuit breaker in order to put \( C_{ph} \) into the grid.

The number of essential measurements to ensure the adequate accuracy [5]:

\[
n = N - \frac{\Delta \sqrt{N^3}}{\Delta} = 44 - \frac{0,05 \sqrt{44^3}}{2,58} = 38
\]

Whereas: 
\[ n \] – the number of essential measurements 
\[ N \] – the number of feeders 
\[ \Delta \] – the selective accuracy (choose \( \Delta =0,05 \) in order to ensure accuracy with high probability)
q- the certain standard is the confidence probability function. If consider that the value (q) corresponds to the probability value
if P = 0.95 then q = 1.96
P = 0.99 then q = 2.58

If \( \dot{U}_A, \dot{U}_B, \dot{U}_C \) - vectors of phase-to-ground voltage before connecting to Cph.

\( \dot{U}_A, \dot{U}_B, \dot{U}_C \) - vectors of phase-to-ground voltage after connecting to Cph

With \( \dot{U}_A = a + jb \); \( \dot{U}_A' = a' + jb' \)

\[ a = \frac{2U^2_A - U^2_B - U^2_C}{6U_f} + U_f; \quad a' = \frac{2U'^2_A - U'^2_B - U'^2_C}{6U_f} + U_f \]

\[ b = \frac{U^2_C - U^2_B}{2 \sqrt{3} U_f}; \quad b' = \frac{U'^2_C - U'^2_B}{2 \sqrt{3} U_f}; \]

Suppose there has a phase-earth fault on phase A, the complete earth fault current of phase A before and after connecting to Cph:

\[ I_{cd} = \dot{U}_A Y_{cd} = \dot{U}_A' (Y_{cd} + Y_f) \Rightarrow Y_{cd} = \frac{\dot{U}_A Y_{ph}}{\dot{U}_A - \dot{U}_A'} \text{ with } Y_{ph} = j\omega C_{ph} \]

\[ Y_{cd} = \frac{(a' + jb').j\omega C_{ph}}{(a-a') + j(b-b')} = \frac{(j\omega C_{ph}(a' - \omega C_{ph}b))(a-a') - j(b-b'))}{(a-a')^2 + (b-b')^2} \]

\[ = \frac{(a'b - b'a).\omega C_{ph}}{(a-a')^2 + (b-b')^2} \quad \text{with} \quad C_{cd} = \frac{[a'(a-a') + b'(b-b')].C_{ph}}{(a-a')^2 + (b-b')^2} \]

infer: \( G_{cd} = \text{Re} \left[ \frac{\dot{U}_A Y_{ph}}{\dot{U}_A - \dot{U}_A'} \right] = \frac{(a'b - b'a).\omega C_{ph}}{(a-a')^2 + (b-b')^2} \)

\[ \omega C_{cd} = \text{Im} \left[ \frac{\dot{U}_A Y_{ph}}{\dot{U}_A - \dot{U}_A'} \right] = \frac{[a'(a-a') + b'(b-b')].C_{ph}}{(a-a')^2 + (b-b')^2} \]

To ensure accuracy, it is necessary to select the auxiliary capacitance (Cph) so that the ground-phase voltages fluctuate minimum, about (10-20)% \( U_{ldm} \). The values of the auxiliary capacitance connected to each feeder is determined by the simulation model, shown in fig 2. According to the simulated results, applied to 6kV feeders of open-pit mines in the QuangNinh region, Cph can be selected as follows: CaoSonC_{ph0}=0.62\mu F; CocSauC_{ph0}=0.32\mu F; DeoNaiC_{ph0}=0.4\mu F; NuiBeoC_{ph0}=0.36\mu F; HaTuC_{ph0}=0.46\mu F.
Based on the measured data, it is possible to identify $G_{cd}$ and $C_{cd}$. The results are listed in Table 1.

**Table 1: The measured results of open-pit mines in the QuangNinh area**

| Order | Temp, °C | Humidity, % | The Converted Overhead line length $L_{dqd}$, km | The Converted Cable length $L_{cqd}$, km | The number of high-voltage motor, unit | The number of transformer, unit | The capacitance, $C_f$, µF | The conductance $G$, $10^4$, Simen |
|-------|----------|-------------|-----------------------------------------------|----------------------------------------|--------------------------------------|-------------------------------|--------------------------|-------------------------------|
| 1     | 17.2     | 80          | 15744                                         | 2027.8                                 | 0                                    | 6                             | 0.506                    | 7,010                         |
| 2     | 16.5     | 75          | 11330                                         | 797.1                                  | 4                                    | 4                             | 0.255                    | 4,451                         |
| 3     | 21.2     | 84          | 4274.5                                        | 1045                                   | 3                                    | 5                             | 0.302                    | 3,794                         |
| 4     | 23.3     | 84          | 5665                                         | 1727.6                                 | 4                                    | 5                             | 0.434                    | 5,301                         |
| 5     | 28.7     | 83          | 3399                                         | 1298.3                                  | 4                                    | 5                             | 0.340                    | 4,186                         |
| 6     | 29.4     | 82          | 7261.5                                        | 1562.9                                  | 3                                    | 7                             | 0.431                    | 5,312                         |
| 7     | 28.6     | 85          | 2303                                         | 2034.8                                  | 0                                    | 9                             | 0.383                    | 5,308                         |
| 8     | 28       | 88          | 7210                                         | 1223.8                                  | 3                                    | 4                             | 0.340                    | 4,483                         |
| 9     | 27.5     | 84          | 1545                                         | 874.6                                   | 5                                    | 5                             | 0.293                    | 3,263                         |
| 10    | 25.5     | 77          | 9064                                         | 2241                                   | 5                                    | 8                             | 0.505                    | 6,154                         |
| 11    | 23.4     | 81          | 9167                                         | 1114.1                                  | 4                                    | 5                             | 0.346                    | 4,733                         |
| 12    | 19       | 85          | 4326                                         | 1062.8                                  | 4                                    | 4                             | 0.303                    | 3,859                         |
| 13    | 17.2     | 80          | 1380.1                                        | 471.7                                  | 2                                    | 8                             | 0.153                    | 2,464                         |
| 14    | 16.5     | 75          | 1946.7                                        | 1045                                   | 4                                    | 4                             | 0.175                    | 3,472                         |
| 15    | 21.2     | 84          | 2343.3                                        | 551.8                                   | 2                                    | 5                             | 0.198                    | 2,569                         |
| 16    | 23.3     | 84          | 3168                                         | 267                                     | 1                                    | 4                             | 0.156                    | 2,056                         |
| 17    | 29.4     | 82          | 2414.9                                        | 320.4                                   | 2                                    | 5                             | 0.156                    | 2,180                         |
| 18    | 28.6     | 85          | 3554.8                                        | 160.2                                   | 1                                    | 4                             | 0.132                    | 1,852                         |
| 19    | 28.6     | 85          | 4481.5                                        | 1012.8                                  | 2                                    | 2                             | 0.261                    | 3,590                         |
| 20    | 28       | 88          | 2012.5                                        | 1094.7                                  | 3                                    | 3                             | 0.261                    | 3,422                         |
2.2. Identification of the Insulating Parameters of The Open-Pit Mine 6kV Grid

2.2.1. Frequency of the Capacitance ($C_f$) and the Insulating Conductance ($G_f$)

Identify the number of capacitance intervals [4]: $k = 1 + 3.22 \cdot \lg(n) = 1 + 3.22 \cdot \lg(60) = 6.9$, select 7 intervals with $\Delta C = 0.0728 \, \mu F$

Applying the Frequency function in Excel calculates the frequency of capacitance and conductance parameters with a given intervals and building the frequency of capacitance and insulating conductance as shown in Figure 3.
The diagram illustrates that the frequency of insulation capacitance $C_f$ and insulating conductance $G_f$ has only one peak, closing to the standard form. Therefore, it is reasonable to examine the insulating parameters of the open-pit mine grids in the Quang Ninh area by months of the year.

### 2.2.2. Testing the Normal Distribution of The Capacitance and The Insulating Conductance

According to the results of the capacitance $C_f$ and the conductance $G_f$ measurement, the testing of the compatibility between the experimental distribution and the theoretical distribution, based on the distribution standard $\chi^2$ [2], is carried out. The characteristic parameters which are represented by the line graph of the theoretical standard distribution density function (dash-dotted line) and the experimental distribution function (solid line) are calculated by using the Descriptive Statistics tool in Excel (Figure 4).

After testing the standard distribution of the capacitance $C_f$ and the insulating conductance $G_f$ found that it is reasonable to investigate the dependence of the capacitance $C_f$ and the insulation conductance $G_f$ of phases to ground with environmental parameters (temperature, humidity) and the structure of grid during the year.
3. Building Dependence of Insulating Capacitance $C_f$ and Insulating Conductance $G_f$ with Environment and Structural Parameters of Open-Pit Mine 6kV Grid

Based on the calculated results (Table 1), the least squares method is an effective and resolvable to build the relationships between the conductance $G_{\text{qd}}$ and insulating capacitance of phase to ground with parameters of environment (temperature, humidity) and the grid structure (the grid conversion length, the number of low-voltage transformers, high-voltage motors).

Select a regression model with parameters $a_0, a_1, a_2, a_3, a_4, a_5, b_0, b_1, b_2, b_3, b_4, b_5, b_6$ from the equations:

$$C_f = a_0 + a_1 D_a + a_2 T_a + a_3 N_{BA} + a_4 N_{dc} + a_5 L_{\text{Tk.qd}} + a_6 L_{C.qd}$$
$$G_f = b_0 + b_1 D_a + b_2 T_a + b_3 N_{BA} + b_4 N_{dc} + b_5 L_{\text{Tk.qd}} + b_6 L_{C.qd}$$

Whereas: $C_f$, $G_f$ - the insulating capacitance and conductance of phase to ground;

$L_{\text{Tk.qd}}$, $L_{C.qd}$ - the converted length of overhead line and cable to cross-sectional area $S = 50\text{mm}^2$; $D_a$ - The humidity of the environment; $T_a$ - the temperature of the environment; $N_{BA}$ - the number of low-voltage transformers connected to the grid; $N_{DC}$ - the number of high-voltage motors connected to the grid.

To predict multiple linear regression model uses Regression, allowing multiple linear regression with a maximum variable of 16, in Excel’s Data Analysis Tool, [3].

Through the results of the variance testing of $C_f$ and $G_f$ measurements and the regression results of $C_f$ and $G_f$, the equations indicating the dependent relationship are received as follows:

$$C_f = -0.45706 + 0.00555 D_a - 0.0005 T_a + 0.00594 N_{BA} + 0.01839 N_{dc} + 7.95 \times 10^{-6} L_{\text{Tk.qd}} + 0.00015 L_{C.qd} \cdot \mu F$$
$$G_f = 0.5298 + 0.006064 D_a - 0.0042 T_a + 0.05288 N_{BA} + 0.064474 N_{dc} + 0.000144 L_{\text{Tk.qd}} + 0.001686 L_{C.qd} \cdot S$$

4. Conclusion

- Building dependence of insulating capacitance $C_f$ and insulating conductance $G_f$ phase to ground with environment and structural parameters of open-pit mine 6kV grid
  $$C_f = -0.45706 + 0.00555 D_a - 0.0005 T_a + 0.00594 N_{BA} + 0.01839 N_{dc} + 7.95 \times 10^{-6} L_{\text{Tk.qd}} + 0.00015 L_{C.qd} \cdot \mu F$$
  $$G_f = 0.5298 + 0.006064 D_a - 0.0042 T_a + 0.05288 N_{BA} + 0.064474 N_{dc} + 0.000144 L_{\text{Tk.qd}} + 0.001686 L_{C.qd} \cdot S$$

- In the experimental formulas, besides the grid’s structural effects (the supply line length, the number of transformers and high-voltage motors), it also takes into account the impact of open-pit mine environment such as humidity and temperature, environmental temperature of the year

- Based on the experimental relationships, it is possible to simulate the actual working status of the grid in order to give necessary conclusions ensuring safety when operating open-pit mine grid as well as accuracy and efficiency calculation, calibration of the single-phase earth-fault protection.
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