Calculation and verification of voltage drop when starting tunnel axial-flow fan

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Abstract. In the electromechanical design of highway tunnels, the calculation of voltage drop during fan start-up is an important part of electrical design, which is related to the safe operation of the whole system, green and energy-saving. The voltage drop involves the setting of substations, and ultimately affects the tunnel engineering scheme. In this study, a theoretical analysis, by calculating the voltage drop when the axial-flow fan starts was implemented. The method was used to calculate and verify the Milashan tunnel section of the 318 National Highway from Linzhi to Lhasa. The method can provide reference for peer designer in similar electromechanical design.

1. Introduction

The electrical equipment of the highway tunnel is powered by AC 380/220V power supply. The normal operation of electrical equipment determines the safety, reliability and comfort of highway tunnel operations.

Tunnels are divided into extra-long tunnels, long tunnels, medium tunnels and short tunnels according to their lengths. Tunnels are classified as follows in table 1.

| Tunnel classification | Extra-long tunnel | Long tunnel | Medium tunnel | Short tunnel |
|-----------------------|-------------------|------------|---------------|-------------|
| Tunnel length L(m)    | L>3000            | 3000≥L>1000| 1000≥L>500   | L≤500       |

According to the requirements of Guidelines for Design of Ventilation of Highway Tunnels and the engineering experience, the single-tunnel two-way traffic tunnel, which is generally larger than 5000m, adopts sectional smoke exhaust or ventilation, and an axial-flow fan is generally installed. Other tunnels generally adopt a longitudinal ventilation scheme to set a smaller-flow jet fan. The axial-flow fan is generally installed in or outside the tunnel. Whether the high-power equipment can start normally will affect the tunnel substation and the layout of the air shaft. This paper makes a theoretical analysis of the calculation of the voltage drop during the starting of the tunnel axial-flow fan and calculates and verifies the Milashan tunnel in the Milashan tunnel section of the 318 National Highway from Linzhi to Lhasa.

2. Specification and requirements

According to Code for Design of Electric Distribution of General-purpose Utilization Equipment GB50055-2011, when the motor starts, its terminal voltage should be able to guarantee the starting torque required by the machine, and the voltage fluctuation caused in the power distribution system should not hinder the normal operation of other electrical equipment. When the AC motor starts, the voltage on the distribution busbar shall comply with the following regulations.
1) The distribution busbar is connected with lighting or other loads sensitive to voltage fluctuations. When the motor is frequently started, it should not be lower than 90% of the rated voltage; When the motor is not frequently started, it should not be lower than 85% of the rated voltage.

2) Unconnected lighting or other loads sensitive to voltage fluctuations on the distribution bus shall not be less than 80% of the rated voltage.

3) When no other electrical equipment is connected to the distribution bus, it can be determined according to the conditions for ensuring the starting torque of the motor; for low-voltage motors, the voltage of the contactor coil should be kept below the release voltage.

3. The definition, calculation and significance of voltage drop

The voltage deviation of the power supply and distribution system refers to the difference between the actual operating voltage $U$ of each point of the system and the nominal voltage $U_N$ of the system under normal operating conditions, expressed as a percentage, namely:

$$\delta U = \frac{U - U_N}{U_N} \times 100\%$$  \hspace{1cm} (1)

When the motor starts, the voltage drop is caused in the power distribution system. The difference between the effective value $U$ of the voltage before starting and the effective value $U_{st}$ of the voltage at the start is called voltage drop, and is expressed by the relative value (ratio to the nominal voltage $U_n$ of the system) or percentage:

$$\Delta u_{st} = \frac{U - U_{st}}{U_n} \text{ or } \Delta u_{st} = \frac{U - U_{st}}{U_n} \times 100\%$$  \hspace{1cm} (2)

The calculation and verification of voltage drop is an important part of the design of power supply and distribution system. In many projects, due to the calculation error or uncategorizing of voltage drop leading to the failure of power supply system, making the equipment cannot start normally, or choosing a larger wire cross section leads to waste of resources. In the design process of the project, the calculation of the voltage drop at the start of the motor is a key part of the electromechanical engineering design.

4. Theoretical calculation

According to *Industrial and Civil Power Distribution Design Manual*, the calculation formula of the bus and motor voltage at the start of the motor is as follows. The calculation is shown in Figure 1.

![Figure 1. Calculation circuit.](image)

Rated input capacity of the starting circuit:

$$S_{st} = \frac{1}{\frac{1}{S_{stM}} - \frac{1}{S_{ih}} - \frac{1}{S_{ih}q_{ih}}}$$  \hspace{1cm} (3)

Busbar voltage relative value:

$$u_{stm} = \frac{S_{km} + q_{ih} + S_{st}}{S_{km} + q_{ih} + S_{st}}$$  \hspace{1cm} (4)

Motor terminal voltage relative value:

$$u_{stm} = \frac{S_{st}}{S_{stm}}$$  \hspace{1cm} (5)

The rated input current of the starting circuit:

$$I_{st} = \frac{S_{ip}}{\sqrt{3}u_{stm}}$$  \hspace{1cm} (6)

The symbols are as follows:
- $S_k$——Transformer primary side short circuit capacity, MVA;
The power distribution system is shown in Figure 2:

The tunnel fan motor technical parameters are as follows:
- Transformer primary side short circuit capacity: $S_r = 200MVA$.
- Transformer capacity: $S_{tr} = 800kVA = 0.8MVA$.
- Transformer reactance relative value: $x_T = 6\% = 0.06$.
- Copper busbars from transformer to low voltage distribution cabinet and low voltage distribution cabinet $L_1 = 12m$.
- Low-voltage cabinet to tunnel axial-flow fan cable $L_3 = 50m$.

Tunnel fan motor technical parameters are following:
- Rated power: $P_{RM} = 315kW = 0.315MW$.
- Rated current: $I_{RM} = 580A = 0.58kA$.
- The tunnel fan adopts the soft start mode, and the starting current is controlled at 2~3 times of the rated current. This calculation is considered according to the maximum multiple.
- Starting current: $I_s = 3I_{RM} = 1.74kA$.
- Other load on the low voltage cabinet bus (power factor is 0.8): $P_{f,h} = 36kW$.

The power distribution system is shown in Figure 2:
5.1 Basic data calculation

According to the known conditions, the wire cross section of the line, the line impedance and the secondary side short circuit capacity are selected.

1) Calculation of rated current on the secondary side of the transformer.

\[ I_{rT} = \frac{S_{rT}}{\sqrt{3} U_{n}} = \frac{800kVA}{\sqrt{3} \times 0.38kV} = 1216A \]

2) Section selection and impedance calculation of copper busbar on secondary side of transformer

According to the rated current calculation of the secondary side of the transformer, the current carrying capacity of the copper busbar on the secondary side of the transformer should be greater than the rated current. The copper busbar of the low voltage cabinet of this project has a specification of \( 4 \times (80 \times 8) + 1 \times (50 \times 5) \). According to the Industrial and Civil Power Distribution Design Manual (third edition), the resistance value of the copper busbar unit length of this specification can be found as 0.031\( m\Omega/m \), Reactance value is 0.17\( m\Omega/m \), then.

\[ R_{L1} = 0.031m\Omega \times 12m = 0.3732\Omega \]
\[ X_{L1} = 0.017m\Omega \times 12m = 0.2004\Omega \]
\[ Z_{L1} = \sqrt{R_{L1}^2 + X_{L1}^2} = 0.0424\Omega \]

3) Calculation of impedance of low-voltage cabinet to tunnel fan cable \( L_2 \)

According to the load capacity of the tunnel fan, the cross section of the low-voltage cabinet to the tunnel fan cable \( L_2 \) is \( 2 \times (3 \times 185 + 1 \times 95) \) when the current carrying capacity and normal operating voltage loss are satisfied. According to the manual, the cross-section cable has a resistance value of 0.1004\( m\Omega/m \) per unit length and a reactance value of 0.07203\( m\Omega/m \), then.

\[ R_{L2} = 0.1004m\Omega/m \times 50m \times \frac{1}{2} = 0.00251\Omega \]
\[ X_{L2} = 0.07203m\Omega/m \times 50m \times \frac{1}{2} = 0.0018\Omega \]
\[ Z_{L3} = \sqrt{R_{L3}^2 + X_{L3}^2} = 0.0031\Omega \]

4) Calculation of active, reactive, and apparent power of other loads connected to the bus of the same environmentally controlled electrical control cabinet.

\[ P_{f\beta} = 36kW \]
\[ S_{f\beta} = \frac{P_{f\beta}}{\cos \phi} = 45kVA = 0.045MVA \]
\[ Q_{f\beta} = S_{f\beta} \times \sin \phi = 0.027Mvar \]

5) Start-up power calculation of tunnel fan

\[ S_{rM} = \sqrt{3} U_{rM} I_{rM} = 0.3817MVA \]

According to the starting current multiple of the tunnel fan, the rated starting capacity is

\[ S_{stM} = k_{st} \times S_{rM} = 1.1451MVA \]

6) Calculation of short-circuit capacity at the secondary side busbar of the transformer.

Figure 2. Tunnel Fan Power Distribution System.
\[ S_{km} = \frac{S_{rT}}{x_T + \frac{S_{rT}}{S_k}} = 12.5\text{MVA} \]

5.2 Calculation and verification of voltage drop when tunnel fan starts

The voltage at the start of the tunnel fan drops. The input capacity of the circuit at the substation when the tunnel fan starts can be calculated:

\[ S_{st} = \frac{1}{\frac{1}{S_{stm}} + \frac{Q_{f,\phi}}{U_{m}^2}} = 1.124\text{MVA} \]

The relative voltage of the busbar on the substation when the tunnel fan starts is:

\[ u_{stm1} = \frac{S_{km} + Q_{f,\phi}}{S_{km} + Q_{f,\phi} + S_{st}} = 91.77\% \]

When the tunnel fan starts, the voltage value on the busbar of the substation is:

\[ U_{stm1} = u_{stm1} \times U_m = 0.35kV \]

The relative voltage at the motor terminals when the tunnel fan starts is:

\[ u_{stm} = u_{stm} \times \frac{S_{st}}{S_{stm}} = 90\% \]

The voltage at the motor terminals when the tunnel fan starts is:

\[ U_{stm} = u_{stm} \times U_m = 0.342kV \]

5.3 Results

According to the second section of Section 2.2.2 of the Code for Design of Electric Distribution of General-purpose Utilization Equipment GB50055-2011, there are lighting or other loads sensitive to voltage fluctuations. When the motor starts frequently, it should not be lower than the rated voltage. 90%; when the motor is not frequently started, it should not be lower than 85% of the rated voltage. The busbar is connected to the lighting load, according to the provisions of the Code for Design of Electric Distribution of General-purpose Utilization Equipment GB50055-2011, the tunnel fan is a type of equipment that is not frequently started, so the voltage on the distribution bus should not be lower than 85% of the rated voltage. According to the calculation, the calculated voltage at the busbar of the low-voltage distribution cabinet at the start of the tunnel fan is 91.77% of the rated voltage, so the requirements are met.

In summary, the voltage drop value of the tunnel axial-flow fan at the start of the tunnel of the Mira Mountain Tunnel in the Milashan Tunnel section of the 318 National Highway from the Linzhi to Lhasa section of the 318 National Highway meets the requirements of the specification and passes the verification.

If the voltage drop value of the tunnel fan does not meet the requirements during the calculation and verification process, some measures need to be taken, such as increasing the cable cross section to reduce the line impedance and setting a short-distance substation to reduce the voltage drop. The tunnel axial flow fan is started to meet the specification requirements.

6. Conclusion

In highway tunnel electrical and mechanical meters, the calculation of voltage drop at the start of high-power equipment is an important part of electrical design, which is related to whether the entire system can operate safely, and involves the layout of substations, ultimately affecting civil engineering. It is expected that the calculation of this project case can provide reference for designers in the same project.

References

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