The Pressure Loss Calculation Method and Application of Portable Fire Extinguishing Equipment for Power System

J.Z. Lu, T.J. Zhou, B. Li, C.P. Wu, Y. Liu

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Abstract — Wildfire nearby transmission has posed a serious threat on power system. Research on portable fire extinguishing equipment has important significance to massive wildfire emergency handling. Structure of the water transfer system of the portable fire extinguishing equipment is analysed. Pressure loss forms of the equipment are elaborated. Basing on actual instance of the water transfer system, a calculation method of pressure loss for long-distance and high-lift transmission is proposed. With the result of the test and CFD simulation, the efficiency and the practicability of the method is verified. A conclusion that transportation distance reaches close to 3000 meters while head reaches 500 meters is drawn. Finally, the application of the portable fire extinguishing equipment in fire prevention of power transmission line results show that massive wildfires can be extinguished quickly. By using the equipment, electric power company’s ability of resisting wildfires has gained remarkable improvement.

Keywords — wildfire; portable fire extinguishing equipment; pressure loss; transportation distance; head

I. INTRODUCTION

With complex climatic conditions, influenced by human interference activities such as spring ploughing, Chinese New Year celebrations, ceremonies during Ching Ming festival and autumn harvest, frequent occurrences of fires disasters near transmission in recent years have caused major property losses in the China’s grid company. Wildfires near transmission not only harm the electric equipment, but also threaten stability of the power system. Trips caused by wildfire at the same time or in succession may cause large area power cutting or breakdown of power network. Control the fire as quickly as possible can stop the fire spreading to transmission.

Currently, the development and improvement of firefighting equipment have been paid wide attention to by researchers at home and abroad. This research results have provided effective methods for fire control [1-4]. As the wildfires disperse in many spots and quite wide areas, combined that ashes are easy to reburn in the wild, the control of wildfires near transmission is carried into effect difficulty. In areas deficient of water, portable fire-fighting equipment should not be used for massive fires. Although fire trucks could carry plenty of water, they are not is unsuitable for wildfires near transmission, due to the traffic inconvenience and low outlet pressure.

Water-series extinguisher is piped to high pressure water mist nozzle by the high pressure piston pump of portable fire extinguishing equipment for power system (referred to in this article portable fire extinguishing equipment). Security of firefighting crews will be threatened and anti-fire efficiency is weak if the location of fires may be beyond the range of transportation distance and head. So, transportation distance and head are the important parameters of portable fire extinguishing equipment. The pressure loss of water-series extinguisher in the pipeline is affected those two parameters markedly. A study on the calculation methods of pressure loss is significant in improving the science and correctness of firefighting work effectively.

II. PRESSURE LOSS FORMS OF PORTABLE FIRE EXTINGUISHING EQUIPMENT

The water conveyance system of portable fire extinguishing equipment includes: high pressure piston pump, connecting pipe, pressure regulating valve, pressure relief valve, fire hose, elbows, and high pressure water mist nozzle, as shown in figure 1.

FIGURE 1. STRUCTURE SKETCH OF PORTABLE FIRE EXTINGUISHING EQUIPMENT.

1-water tank; 2-high pressure piston pump; 3-piezometer; 4-safety valve; 5-pressure regulating valve; 6-truck-mounted connecting pipe; 7-fire hose; 8-lance; 9-high pressure water mist nozzle

By applying the Bernoulli equation, which is shown as formula (1), pressure loss of portable fire extinguishing equipment includes the route loss and the local loss.

$z_1 + \frac{p_1}{\rho_g} + \alpha_1 \frac{v_1}{2g} = z_2 + \frac{p_2}{\rho_g} + \alpha_2 \frac{v_2}{2g} \quad (1)$

From formula (1) and figure 1, the pressure loss forms of the equipment can be drawn, as shown in figure 2.
Where, $L$ is the length of fire hose, $d$ is internal diameter of fire hose, $\lambda$ is the friction factor, $\zeta_i$ is local drag coefficient and $v$ denotes a mean velocity of the fluid in the conduit.

III. PRESSURE LOSS CALCULATION AND SIMULATION OF PORTABLE FIRE EXTINGUISHING EQUIPMENT

A. Flow Analysis of Water-series Extinguisher

Reynolds number is an important parameter reflecting the fluid flow characteristics in the pipe. When the Reynolds number is small, viscous forces play host to the force between liquid particles and a fluid flows in parallel layers, with no disruption between the layers. While if the Reynolds number is large, the flowing liquid is in a turbulence state, thus inertia forces play host to the force between liquid particles.

The sectional area and velocity equals everywhere along the fire hose. Formula 3 is commonly used for calculation of velocity of flow.

$$v = \frac{4Q}{\pi d^2}$$

So, if the average flow of fire hose is 20.3 litres per minute and the diameter of pipeline is 16mm, the velocity of water-series extinguisher is 1.659 m/s.

At 20℃, the dynamic viscosity of water-series extinguisher is $1.005 \times 10^{-3} \text{ Pa.s}$. According to the formula of calculation of Reynolds number, it can be deduced that the Reynolds number is 26411 and the flowing liquid is in a turbulence state.

B. Calculation of the Route Loss

The inner surface roughness of the fire hose measures 0.010 mm and the relative roughness is 0.000625. Thickness viscous sub-layer is calculated using semi-empirical correlation, as shown in formula 4.

$$\delta = \frac{34.2d}{Re^{0.875}} = 7.39 \times 10^{-2} > \Delta = 0.010 \text{ mm}$$

This shows that the fire hose is hydraulic smooth pipe at this condition. So, the water-series extinguisher flow condition corresponds to the third interval of Nicholas' curve. Iterative method was used to calculate the friction factor of Prandtl-Schlichting formula which is shown in formula 5.

$$\frac{1}{v_c} = -2.01g \left(\frac{2.51}{Re^{0.875}}\right)$$

Take the Reynolds number $Re$ into (5) perform iterative calculation, then get that $\lambda = 0.0241$.

Using formula (2) gains that the frictional head loss of 3000 m pipe is 621 m (water column height), that is the frictional head loss of 3000 m pipe is 6.21 MPa.

Simulate the water delivery system of portable fire extinguishing equipment based on Fluent 6.3.26, use periodic boundary conditions, calculate the pressure loss of unit length of water pipe under a certain flow, then, we can get the frictional pressure loss of 3000 m pipe. Aiming to the Reynolds number Re of fluid flowing in the pipe, calculate by using Spalart-Allmaras model and $\kappa-$e model respectively, and compare the result of numerical modelling with that of calculation following Nikuradse experience curve method.

**FIGURE II. VELOCITY DISTRIBUTION THROUGH ANALOG CALCULATION BY USING S-A MODEL AND $\kappa$-$\varepsilon$ MODEL.**

**TABLE I. PRESSURE LOSS UNDER DIFFERENT TURBULENCE MODEL.**

<table>
<thead>
<tr>
<th>calculation model</th>
<th>Pressure Lose</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nikuradse Curve</td>
<td>6.21MPa</td>
<td></td>
</tr>
<tr>
<td>Spalst-Allmaras Model</td>
<td>7.20MPa</td>
<td>15.9%</td>
</tr>
<tr>
<td>$\kappa$-$\varepsilon$ Model</td>
<td>8.40MPa</td>
<td>35.26%</td>
</tr>
<tr>
<td>RNG-$\kappa$-$\varepsilon$ Model</td>
<td>7.25MPa</td>
<td>16.7%</td>
</tr>
</tbody>
</table>

Table 1 indicates that Spalst-Allmaras Model is more accurate to simulate the pressure loss of the portable fire extinguishing equipment than others, whose calculation accuracy could satisfy the requirement of design and application of portable fire extinguishing equipment. The reason is that Spalst-Allmaras Model is effective to simulate low Reynolds number flow, and its demand on grid partition is not high. According to Fig3, the velocity gradient near wall in Spalst-Allmaras Model is smaller than that in $\kappa$-$\varepsilon$ Model. Turbulent fluctuation contributes to dramatic power exchange among the particle of fire extinguishing agent and uniform distribution of velocity, which better meets the velocity distribution formula 6 of fluid in the core of turbulence in hydraulically smooth region.

$$\frac{h}{u^*} = 2.5 \ln \frac{u^* y}{v} + 5.5$$

C. Local Loss Analysis

The local loss is due to the change of the water hose sectional area, which causes the change of flow direction, the redistribution of velocity and the loss resulting from the momentum exchange among mass points by collision. The local loss of the water delivery system of mobile fire-fighting platform includes 5 forms, among which are sudden expansion, sudden contraction, bend, folded hose and sluice valve.
According to the values of the coefficients of local loss in Table 2 and combined with the calculating expression (2) for route loss and local loss, the local pressure loss of transmission line mountain fire, the safety and rapidity of mobile firefighting platforms can be fulfilled by only calculating the route pressure loss.

IV. PORTABLE FIRE EXTINGUISHING EQUIPMENT FIELD TEST

A. Test Condition

The location of the test is in the Xiaoshajiang town, Longhui country, Hunan Province, located in the northwest of Longhui, in the middle of the Xuefeng mountain. The moving firefighting platform tests at a point chosen at the foot of the mountain near the Pufo temple, the altitude of which is 1123 meters above sea level measured by GAR MINGPS60. The end of the test is at the top of the mountain, near the Pufo temple. The altitude is 1623 meters above sea level. And the difference between the two altitudes is 500 meters. Measurement of the output atomization state and pressure of different altitude can be completely atomized extinguishing. Influence of the pressure resistance, its range decreases instead.

B. Test Data and Analysis

<table>
<thead>
<tr>
<th>No.</th>
<th>Diameter expanding</th>
<th>Diameter reduction</th>
<th>Pipe bending</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>( \phi_1 = \frac{(1 - \frac{A_2}{A_1})^2}{2} )</td>
<td>( \phi_2 = \frac{1}{2} (1 - \frac{A_2}{A_1}) )</td>
<td>( \phi_3 = 0.131 + 0.163 \left( \frac{d}{R} \right) \left( \frac{\theta}{90} \right)^2 )</td>
</tr>
<tr>
<td>2</td>
<td>( h_1 = \phi_1 \times \frac{1}{2} \times v_1^2 )</td>
<td>( h_2 = \phi_2 \times \frac{1}{2} \times v_1^2 )</td>
<td>( h_3 = \phi_3 \times \frac{1}{2} \times v_1^2 )</td>
</tr>
</tbody>
</table>

According to the test data, the effects of mobile firefighting platforms in mountain firefighting are negligible compared with the route pressure loss. While dealing with the urgency of transmission line mountain fire, the safety and rapidity of mobile firefighting platforms can be fulfilled by only calculating the route pressure loss.

V. APPLICATION OF PORTABLE FIRE EXTINGUISHING EQUIPMENT IN POWER SYSTEMS

According to the history statistics of wildfires, massive mountain fires often occurred during the period of Tomb-sweeping Day all around China, which resulted in the trips of transmission lines and the severe threat to the safe operation of the grid[8]. During the period of Tomb-sweeping Day in 2014, State Grid Hunan Electric Power Company deployed five portable fire extinguishing equipment, and the total area of extinguished open fires was 3,500m² in April 4-5. The lines of 110kV and above of the Hunan grid did not suffer from the accidents of mountain fire trip, which set a record that there was no trip occurring in the Hunan grid during a no-rain Tomb-sweeping Day, marking a great breakthrough of the technology against wildfires of the grid, and ensured a strong support for the safe and stable operation of the large power grid. The application of the portable fire extinguishing equipment means that the characteristics of the equipment includes safe drive, long water-delivery distance, high lift and good performance for fire-fighting, which can solve the problems of the bad traffic at the sites of transmission line mountain fire and the tough access to water, and fill up the gap of equipment for transmission line mountain firefighting in China.

VI. CONCLUSION

Aiming at the existing problem that forest fire near transmission line, water delivery distance and lift, this paper analyzes the pressure loss of portable fire extinguishing equipment through the combination of theoretical calculation, wild field test and numerical simulation, which effectively guides the design and field application of portable fire extinguishing equipment and has made the conclusion that the water delivery distance of portable fire extinguishing equipment can reach 3000m and the vertical lift of that can reach 500m at the same time. The practical application of portable fire extinguishing equipment in power system indicates that the equipment possesses several advantages including safety driving and user-friendly control, which has settled the problem that it is difficult for us to get water in the process of handling forest fire near transmission lines. At the meantime, it dramatically reduces the number of trip caused by forest fire related transmission lines and has obviously enhanced the ability to defending forest fire, which has a broad application and dissemination value.
REFERENCES


