Experimental Investigations on Combustion Behaviors of Live PVC Cables

Liufang Wang1, Jiaqing Zhang1,*, Bosi Zhang2, Min Liu3, Minghao Fan1, Qiang Li4

1State Grid Anhui Electric Power Research Institute, Hefei, China
2China University of Labor Relations, Beijing, China
3State Grid Zhejiang Electric Power Research Institute, Hangzhou, China
4Chinese People's Armed Police Forced Academy, Langfang, China

*Corresponding author e-mail: dkyzjq@163.com

Abstract. This paper investigated the combustion behaviors of live PVC cables with overload currents experimentally. The smoke coefficient of released smoke and the released gas concentration were examined. The results indicate that the combustion of live PVC cables can be divided into four stages, i.e., core exposed with a little smoke, obvious flame, maximum smoke and smoke depress. For most cases, using blue laser is better than using rad laser, since the extinction coefficient of the rad laser was larger than that of the blue laser. The response time of the detection of the released typical gases due to cable pyrolysis decreased and the peak values of the typical gases increased with the overload currents. In addition, the time to reach the peak value of gas concentration also decreased with the overload currents.

1. Introduction

Fire safety of cables is of great significance, due to the wide application of cables in power distribution facilities [1]. Cables have been contributed to many fire accidents in electric power facilities over the years [2-3].

Many studies have been devoted to combustion characteristics of cables, using cone calorimeter test, differential scanning calorimetry and simultaneous thermal analysis [4-6]. However, those studies were all conducted with no currents. It has been indicated that the influence of current variable on live cable fire should be taken into account when enact the electric safety [7]. Therefore, the combustion behavior of live cables should be investigated, leaning close to the real situation of cable fire accidents.

This paper investigated the combustion behaviors of live NH-KVV cables (3×2.5), i.e., Cu, PVC insulated, PVC sheathed, refractory control cable, with different overload currents. The smoke coefficient of released smoke and the released gas concentration were also examined.

2. Experiments and materials

This paper considered both of the aim of the research, i.e., the combustion process with live currents, and the actual use conditions of cables. Owning to the convenience of the experiment and economical efficiency, a experimental platform according to the typical size of cable trench has been constructed. As shown in Figure 1, the size of the cabin is 2 m (L)×0.8 m (H)×0.8m (W).

The smoke exhaust system was installed to accumulate the released smoke in experiments. The exhaust system were consist of smoke exhaust hood, the exhaust pipe and the smoke exhaust fan. Both
the port used to get smoke sample and the laser equipment were set on the sampling pipe. The flow rate of the smoke in the sampling pipe was uniformed when the length of the pipe was at least 12 times of its diameter. Therefore, the length of pipe was 1.4 m, and the port used to get the smoke sample and the laser equipment were set at 1.1 m and 1.2 m far from the smoke hood on the sample pipe, respectively. The smoke exhaust fan with the ventilation rate of 273 m$^3$/h was installed at the end of the pipe. There was an inlet port at the lower space of the platform.

The cable tested is NH-KVV (3×2.5), i.e., Cu, PVC insulated, PVC sheathed, refractory control cable, and the rated current is 19 A. The overload currents including 5, 6, 7 times of rated currents are tested.

Figure 1. The experimental platform.

3. Results and Discussion

3.1. Combustion Stages and Behaviors

Figure 2 shows the combustion stages and behaviors of live pvc cables with 6 times rated currents. From the figures, for NH-KVV cables, it can be seen that the core exposed obviously during the whole test process. The test procedure can be divided into four stages, i.e., a) core exposed with a little smoke (118 s); b) obvious flame (168 s); c) maximum smoke (286 s) and d) smoke depress (391 s).

The process of smoke release was similar in all experiments under different overload currents, as discussed previous. Generally, the time from initial smoke release to interruption of the line was decreased with the overload currents. With the overload current, the temperature of core increased gradually. Both the melted insulating material and the sheathing material began to release smoke when the temperature of the core was high enough, and the area of core deposed in high-temperature environment increased. When most of the insulating materials and the sheathing materials were consumed due to the process of pyrolysis, the amount of released smoke decreased.
The curves of smoke densities along with time in the experiments with 6 times rated currents are illustrated in Fig. 3. The four stages, i.e., a) core exposed with a little smoke; b) obvious flame; c) maximum smoke and d) smoke depress were also marked in Fig. 3. The smoke density was represented by the extinction coefficient in the present study. The smoke density was proportional to the extinction coefficient. The delay time between a small quantity of smoke released and the later equipment detected the variation of the smoke density was 11 s. At the initial stage, the smoke density increased quickly due to the pyrolysis of the insulating material and sheathing material. The smoke density began to decreased at almost 300 s. The duration of this experiment was more than 700 s, and the interruption was not happened until of the experiment. From Fig. 3, the extinction coefficient of the rad laser was almost equal to that of the blue laser at the growth stage, and the extinction coefficient of the rad laser became smaller than that of the blue laser at the decay stage. Moreover, the peak extinction coefficient of the rad laser was obviously lower than that of the blue laser.

3.2. The Smoke Coefficient of Released Smoke

The smoke coefficients of released smoke with different times of currents are shown as Figure 4. It was found that the interruption was not happened in the experiments under the 5 and 6 times of rated currents. When the overload currents were 7 times of the rated currents, the interruption of line was observed during the experiment duration. When the overload current was five times of the rated currents, the release rate of smoke was slow than that in the experiments with 6 and 7 times of the rated currents, and the extinction coefficient of the rad laser was larger than that of the blue laser in
this experiment. In the experiments with higher overload currents, the extinction coefficient of the red laser was smaller than that of the blue laser.

With the increase of the overload currents, the response time of the laser equipment decreased. The peak of smoke density increased, and the time to reach the peak value deceased with the overload currents. Moreover, the ratio of the extinction coefficient of the red laser to the extinction coefficient of the blue laser also increased with the overload currents, and this ratio was less than 1 in the experiment with the overload current of 5 times of the rated currents.

![Figure 4](image-url) The smoke coefficients of released smoke with different times of currents.

3.3. The Released Gas Concentration

The released gas concentration with different times of currents are shown as Figure 5. The gas concentrations were derived from the smoke sample by using the gas analyzer. The concentrations of CO, CO₂ and the NOₓ were explored.

The response time of the detection on the gases decreased with the overload current. According to the results of CO and CO₂ concentrations, the peak of the gases increased with the overload currents. As we discussed previous, the interruption was not found in the experiments with 5 times of the rated currents. Therefore, the increase rates of CO and CO₂ concentrations were much slower in the experiment with 5 times of the rated currents that those in the experiments with higher overload current. The experiment duration was decreased with the overload currents. The peak of gas concentrations was much higher in the experiment with 7 times of the rated currents than those in the experiments with lower overload currents. There were two peaks in the CO₂ concentration curve in the experiment with 7 times of the rated currents, and the second peak was appeared after the interrupting in the experiment with 6 times of the rated currents. The experimental results on NOₓ concentration was different from those derived according to the CO and CO₂ concentrations. The NOₓ concentration of the experiment with 5 times of the rated currents was obviously higher than that of the experiment with 6 times of the rated currents.

![Figure 5](image-url) The CO and CO₂ concentrations with different times of currents.
4. Conclusion
This paper investigated the combustion behaviors of live NH-KVV cables, i.e., Cu, PVC insulated, PVC sheathed, refractory control cable, with different overload currents. The smoke coefficient of released smoke and the released gas concentration were also examined. The main conclusions are as follows:

1) The combustion of live PVC cables can be divided into four stages, i.e., core exposed with a little smoke, obvious flame, maximum smoke and smoke depress.

2) The interrupting was not found in the experiment with 5 and 6 times of rated current, and the interrupting was happened in the experiments with higher overload currents. Under 5 times rated current, the extinction coefficient of the rad laser was larger than that of the blue laser. In the experiments with 6 and 7 times rated current, the rad laser was smaller than that of the blue laser.

3) The response time of the detection of the released typical gases due to cable pyrolysis decreased and the peak values of the typical gases increased with the overload currents. In addition, the time to reach the peak value of gas concentration also decreased with the overload currents.

Acknowledgments
This work was financially supported by the Science and Technology Project of State Grid Corporation of China and Anhui Provincial Natural Science Foundation (Grant No. 1408085MKL94).

References
[1] J.Q. Zhang, M.H. Fan, W. Li, et al., Fire Safety of Cables in Power Grid: Tracking Combustion Test Standards of Cables and New Insights on Test Framework, International Council on Large Electric Systems, CIGRE 2016, B1-214.
[2] K.B. McGrattan, Cable Heat Release, Ignition, and Spread in Tray Installations During Fire (CHRISTIFIRE): Phase 1, Horizontal Trays, NUREG/CR-7010, Vol. 1, Office of Nuclear Regulatory Research, United Sates Nuclear Regulatory Commission, 2012.
[3] O. Keski-Rahkonen, J. Mangs, Electrical ignition sources in nuclear power plants: statistical, modelling and experimental studies, Nuclear Engineering & Design, 213 (2002) 209-221.
[4] J.Q. Zhang, M.H. Fan, X.F. Du, et al., Tracing and Analysis on Combustion Test Standards of Electrical Wires and Cables, Insulating Materials, 48 (2015) 6-11.
[5] J.Q. Zhang, B.S. Zhang, M.H. Fan, et al., Effects of External Heat Radiation on Combustion and Toxic Gas Release of Flame Retardant Cables, Materials Science Forum, 898 (2017) 2392-2398.
[6] J.Q. Zhang, L.F. Wang, M.H. Fan, Thermal Degradation of Flame Retarded Polyvinylchloride Cable Sheath in Air Atmosphere, IOP Conf. Series: Materials Science and Engineering, 199 (2017) 012071.
[7] J.Q. Zhang, B.S. Zhang, L.F. Wang, et al., The State of the Art of Combustion Behavior of Live Wires and Cables, Materials Review, 31 (2017) 1-9.