Design and Application of Dynamic Line Rating System for Distribution Lines

Anfeng Jiang, Zhengkai Jiang, Huabin Dai, Jin Liu, Lumin Fu, Lei Tang
State Grid Shanghai Pudong Electric Power Supply Company

***Abstract*—In recent years, the load level of Pudong Power Grid is increasing year by year. In the summer peak period, the allowable capacity of the distribution line is the bottleneck of the power distribution network. In order to improve the power supply capacity of the existing heavy load distribution lines and the utilization efficiency of the line equipment assets, a dynamic line rating system, this can be applied to the insulated conductors and bare wires of the distribution lines. The system is designed and applied to the 35kV and 10kV overhead distribution lines in the Pudong power grid. Through the operation of last year's summer peak, the system can increase the capacity of the distribution line by about 20%. It can provide a scientific reference for the dispatching and inspection personnel to take the instantaneous safety measures at the peak time of the power consumption, and reduce and even eliminate the unnecessary load reduction operation in some cases.**

***Index Terms*—Distribution lines, insulated conductors, current carrying capacity, conductor temperature, dynamic line rating system**

I. Introduction

In recent years, with the rapid growth of regional economy, the load level of Pudong power grid during the summer peak is increasing year by year. In the peak period of electricity consumption or failure time of individual overhead lines, the allowable load of some lines becomes the bottleneck to restrict the power supply of the power grid. There is no concrete cutting scheme for the heavy load line during the summer of 2017. In the past, the method of increasing line voltage grade and increasing line return is used to increase the line load capacity. However, this method has a huge investment, long construction period, and will increase the area of the line corridor, which is difficult to adopt.

Dynamic line rating is a method that does not change the existing physical parameters of the overhead line, and it has been successfully used in the 220kV-750kV EHV transmission lines at home and abroad [1-3]. According to the prediction of Pudong dispatching centre, there were one 35 kV and five 10 kV expected heavy load distribution lines in 2017. Therefore, in the context of building the intelligent interactive online monitoring of the world's first-class distribution network, in order to improve the power supply capacity of the existing heavy load lines, Pudong Company has designed a dynamic line rating system which can be applied to the insulated conductors and bare wires of the distribution lines.

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II. Principle and Composition of Dynamic Line Rating System

A. The Principle of Dynamic Line Rating System

The difference between the dynamic line rating system used for distribution lines and those used for EHV transmission lines are:

1. The calculation model of maximum current carrying capacity of insulated wire is established. Most of 10kV overhead lines are insulated conductors, and the previous calculation model of ultra high pressure bare wire is no longer applicable.

2. No traverse sag monitoring device is used. Under high load condition, temperature rise leads to sag variation of EHV lines much larger than that of 10kV-35kV overhead distribution lines.

Transmission capacity of lines is limited by fatigue and deformation of wires and fittings at high temperatures. In the actual operation of the power grid, in order to prevent the overheating failure of the transmission line load increasing, the domestic and foreign power departments adopt the limit value of the static heat capacity of the line as the maximum allowable discharge of the wire in the design of the line.

The maximum flow rate of wire and the state of wire (wire temperature, tension, sag and so on) and weather conditions (ambient temperature, sunshine, wind speed, etc.), the most stringent conditions are used in the design of the maximum load of overhead lines in the past and abroad for the safety margin. For example, the maximum allowable capacity of domestic overhead lines is designed to adopt the GB50545-2010 and DL/T 5092-1999 [4-5]. The regulations stipulate that the surface of steel core aluminum strands and steel core aluminum alloy strands can be used at +70 ℃, and the ambient temperature should be used most. The highest average temperature of the high temperature month (Shanghai ambient

temperature is 40 ℃), the wind speed should adopt 0.5m/s, and the solar radiation power density should adopt 1000W/m2 [6-7]. However, from the actual operation of the power grid, the external meteorological conditions of the power grid are much better than the most stringent conditional parameters for most of the time. This provides the possibility of appropriately increasing transmission capacity in the short term.

The line rating methods are divided into static line rating method and dynamic line rating method. The static line rating method does not change the physical parameters of the wire. In the design, the permissible temperature of the wire surface is increased from 70 ℃ to 80 ℃ [8-9]. This method breaks through the provisions of the current technical regulations and increases the running risk of the line.

The principle of dynamic line rating is to install on-line monitoring device on the line. Under the condition of the current technical regulations (the temperature limit of 70℃), the wire state (wire temperature) and meteorological conditions (ambient temperature, sunshine, wind speed and so on) are monitored, and the data collected in time are replaced by the overhead line. The real time maximum allowable carrying capacity of the overhead line is obtained through the flow calculation model [9-10].

According to the prediction of Pudong regulation center, one 35kV and five 10kV distribution lines were expected to be heavy load.

According to the parameters provided by the equipment account and control center, the maximum allowable capacity of the overloaded overhead line is calculated by using the method based on design specification and design standard of electric wire and cable carrying capacity. First order fault repair state: high temperature 40 ℃ is adopted, two grade failure repair state 37 ℃ is adopted, three grade failure repair state 35 ℃ is adopted.

According to the above calculation, it is concluded that the maximum allowable discharge of the overhead line provided by the scheduling is the design value of the ambient temperature 25 ℃ in the selection design technology of DL/T 5222-2005 conductor and electrical apparatus, because the environment temperature is high and the maximum allowable discharge of the overhead line under the condition of the summer three fault repair state temperature is gradually reduced.

TABLE I THE MAXIMUM ALLOWABLE CARRYING CAPACITY OF HEAVY HAUL LINES IN THE THREE LEVEL OF EMERGENCY REPAIR DURING PEAK SUMMER SEASON

Line type	The maximum allowable carrying capacity of heavy haul line			
	25 ℃	35 ℃	37 ℃	40 ℃
LGJ-185	515	510	475	461
LGJ-120	375	380	305	296
JKLYJ-10/120	375	340	270	262

As the maximum allowable flow design value of the overhead line adopts the most severe external weather condition parameters, in order to analyze the effect after the dynamic line rating system, according to the actual operation of the power grid, it is assumed that the wind speed increases, the solar radiation power density decreases, and the heavy load overhead before and after the dynamic line rating system is calculated.

B. The Structure of Dynamic Line Rating System

The structure of distribution line dynamic line rating system used in this project is shown in Figure 1. The traversing monitoring device can measure the environmental parameters needed for the real-time measurement of the current and the discharge of the wire. The traversing device sends the data to the public network application server through the data card, and the software is written on the application server to calculate the maximum in real time. The user obtains the maximum allowable carrying capacity real-time computation result through the database server.

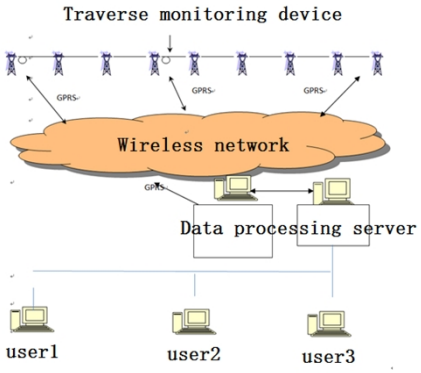

Fig. 1. Structure of dynamic line rating system of distribution line

The five in one line rating ball used in the system is shown in Figure 2 as a traversing device, which can be installed on the overhead wire. The ball could measure the five parameters of wire temperature, operating current, ambient temperature, wind speed and illumination in real time. The software interface of power distribution line dynamic line rating system is shown in Figure 3.

Fig. 2. The appearance and internal structure of five in one line rating ball

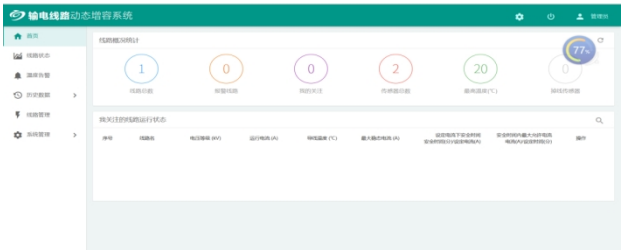

Fig. 3. Software interface for dynamic line rating system of distribution lines

III. Math Application of Dynamic Line Rating System

A. Installation of Dynamic Line Rating System

According to the PMS account information analysis and installation site field investigation, the dynamic line rating system is installed on 35kV line under power cut condition and on 10kV lines in live work. The site installation photos are shown in Figure 4 and the actual operation photos of the system are shown in Figure 5.

Fig. 4. Photos of dynamic line rating system installation on 35kV and 10kV distribution lines

Fig. 5. Photos of dynamic line rating system actual operation on 35kV and 10kV distribution lines

B. The Daily Operation of Dynamic Line Rating System

The operation data of 35kV bare conductor and 10kV insulated conductor distribution lines were analyzed. Figure 6 and 7 is the daily load and the allowable flow rate curve of the 35kVdistribution line. The maximum daily load is 253.9A far below the minimum allowable discharge 646.8A (the maximum value is 1021A). The maximum temperature of the line is 36.2 ℃ (the regulation limit is 70 ℃, as shown in Figure 7). According to the rated current 515A of the line, the maximum daily load rate of the line is only 49.3%. Therefore, according to the meteorological conditions of the day, the power supply potential of the line is huge.

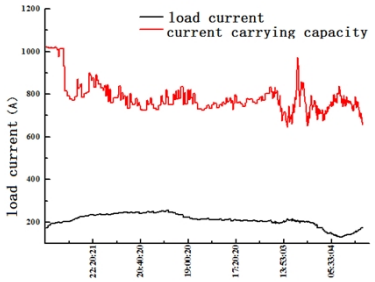

Fig. 6. Daily load and permissible flow chart of 35 kV distribution line

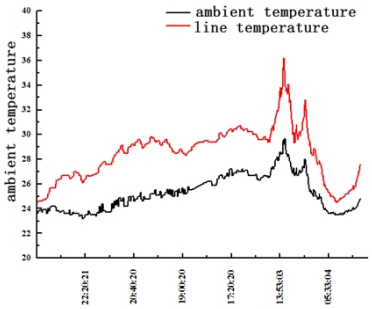

Fig. 7. Daily curve of temperature 35 kV distribution line

Figure 8 is the daily load and permissible flow chart of the 10kV line. The maximum daily load is 109.7A far below the line allowable discharge minimum value 375.9A (maximum 426.5A), and the highest temperature of the line conductor at that day is 34.5 C (the regulation limit is 70 C, as shown in figure 9). According to the rated current 325A of the line, the maximum daily load rate of the line is only 33.8%.

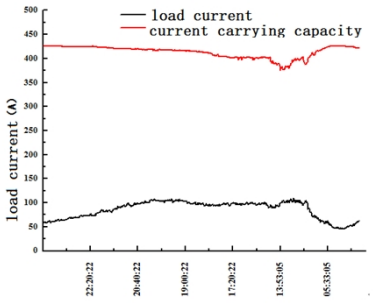

Fig. 8. Daily load and permissible flow chart of 10 kV distribution line

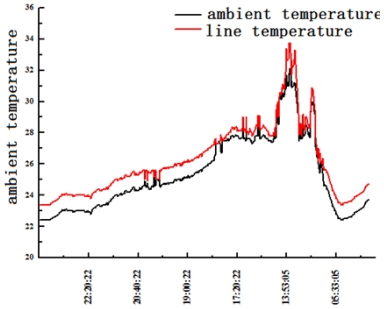

Fig. 9. Daily curve of temperature 10 kV distribution line

C.The Response Characteristic Test of Dynamic Line Rating System

According to the overhead line traffic information provided by the scheduling, one 10kV distribution line is selected as the reference of the recent maximum load day in June 1st. In June 29th, the reliability and response characteristics of the installation dynamic line rating system are tested.

Fig. 10.Increase capacity of running temperature load curve

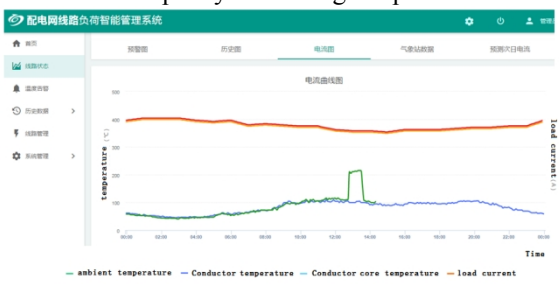

Fig. 11. Load and flow chart of 10 kV distribution line

The results show that since the installation of the system, the abnormal phenomena such as device drop and data error have not been found, and the running situation of the line rating and monitoring background is good. It can capture the changes of the overhead line and temperature rise in real time, and provide valuable reference data for the personnel of inspection and dispatching.

D.The Summer Peak Period Operation of Dynamic Line Rating System

Since the system has been put into operation, it runs well, and the online rate is >97%.

In the summer peak period, the maximum temperature of 45 ℃, the maximum running current of the 35 kV distribution line is 525A and 10 kV distribution line is 334A, which can increase the capacity of the distribution line by about 22% and 19%, respectively. The result of the 10 kV distribution line is shown in Figure 12.

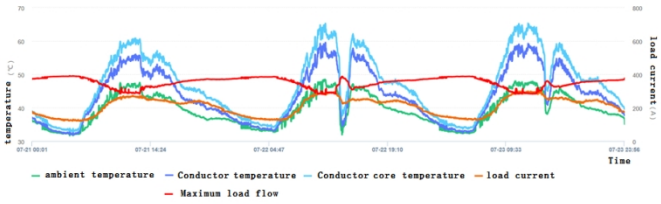

Fig. 12. The curve of the maximum temperature 10 kV distribution line in the summer peak period

IV.CONCLUSION

In the background of building the intelligent interactive online monitoring of the world class distribution network, in order to improve the heavy load power supply capacity of the existing distribution lines and the utilization efficiency of the line equipment assets, Pudong has applied the dynamic line rating system to one 35 kV and five 10 kV expected heavy load distribution lines. After daily operation and increasing line load test, the reliability and response characteristics of the dynamic capacity increase system are tested. The results show that the system has not found abnormal phenomena such as device drop, data error and so on. Through the operation of last year's summer peak, the system can increase the capacity of the distribution line by about 20%.The running situation of the monitoring background is well proved, and the changes of the overhead line and temperature rise can be caught in real time. The system had played a role in the summer of 2017, and provides scientific reference for the dispatch and inspection personnel to seize the opportunity to take instantaneous safety increase in the peak time. At the same time, it can reduce or even eliminate the unnecessary load reduction operation in some cases.

REFERENCES

[1] M. Matus, D. Saez, M. Favley, et al. , “Identification of critical spans for monitoring systems in dynamic thermal rating,” IEEE Trans. Power Del., vol. 27, No. 2, pp. 1002-1009, 2012.

[2] J. Hosek, P. Musilek, E. Lozowski, et al. , “Effect of time resolution of meteorological inputs on dynamic thermal rating calculations,” IET Generation, Transmission & Distribution, vol. 5, No. 9, pp. 941-947, 2011.

[3] K. S. Wang, G. H. Sheng, K. Wang, et al., “Operation risk assessment of a transmission line dynamic line rating system,” Automation of Electric Power Systems, vol. 35, No. 23, pp.11-15, 2011.

[4] G. Ke, L. Z. Yi, S.X. Zhou, et al., “Study of capacity-increase for simultaneous AC-DC transmission based on double circuit AC

transmission line," Power System Protection and Control, vol. 41, No. 6, pp. 25-31, 2013.
[5] L. K. Liang, X. S. Han, Y. L. Wang, et al., "Online valuation of transmission line loadability," Transactions of China Electro technical Society, vol. 28, No. 2, pp. 279-284, 2013.
[6] DL/T5092-1999 technical code for designing 110~500 kV overhead transmission line. China Electric Power Press, 1999.
[7] F. H. Wang, J. M. Wu, Z. J. Jin, et al., "Transmission capacity analysis of transmission line when considering the reactive power compensation of power system," Power System Protection and Control, vol. 39, No. 18, pp. 105-109, 2011.
[8] Zhang Q. P., Z. Y. Qian, "Study on real-time dynamic capacity-increase of transmission line," Power System Technology, vol. 29, No. 19, pp. 18-21, 2005.
[9] IEEE Std 738-2006 IEEE standard for calculating the current-temperature relationship of bare overhead conductors. 2006.
[10] Y. H. Bao, C. Y. Feng, T. S. Xu, et al., "Online security and stability comprehensive auxiliary decision-making of power system," Automation of Electric Power Systems, vol. 39, No. 1, pp. 104-110, 2015.

Anfeng Jiang was born in Urumqi, China, in 1987. He received the M.Eng. and Ph.D. degrees in electrical engineering from Shanghai Jiao Tong University, Shanghai China, in 2012 and 2015. He is the electrical engineer in State Grid Shanghai Pudong Electric Power Supply Company form 2015.
His research is dedicated to lightning protection, operation and maintenance of distribution power grid.