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Experimental Study on the Cyclic Ampacity and Its Factor of 10 kV XLPE Cable

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ABSTRACT

The load varies periodically, but the peak current of power cable is controlled by its continuous ampacity in China, resulting in the highest conductor temperature is much lower than 90℃, the permitted long-term working temperature of XLPE. If the cable load is controlled by its cyclic ampacity, the cable transmission capacity could be used sufficiently. To study the 10 kV XLPE cable cyclic ampacity and its factor, a three-core cable cyclic ampacity calculation software is developed and the cyclic ampacity experiments of direct buried cable are undertaken in this paper. Experiments and research shows that the software calculation is correct and the circuit numbers and daily load factor have an important impact on the cyclic ampacity factor. The cyclic ampacity factor of 0.7 daily load factor is 1.20, which means the peak current is the 1.2 times of continuous ampacity. If the continuous ampacity is instead by the cyclic ampacity to control the cable load, the transmission capacity of the cable can be improved greatly without additional investment.

Keywords: XLPE Cable; Experiment; Cyclic Ampacity; Software

1. Introduction

Power cable has been widely used in urban power grids. With the rapid economic development in China, the transmission capacity of power cable needs to be improved. However, it is extremely difficult to construct new cables due to the high cost and the dense underground pipeline in urban [1]. Therefore, it is very important to take full advantage of the cable capacity.

In China, the cable load is adjusted based on its rating, i.e. the continuous ampacity. However, the actual current in operation cable is not continuous but showing a periodical variation. What's more, the daily load curve shape doesn't change a lot within a relatively long period of time (such as one month). Due to the existence of thermal capacity of cable system (including the cable and its surrounding soil), the cable conductor temperature (namely insulation temperature) is delayed hours after the load changes, the delay time depend on its thermal time constant. In this situation, if the cable peak current is controlled by its continuous ampacity, the highest cable conductor temperature will be much lower than 90℃, which is the permitted long-term working temperature of XLPE, resulting in a waste of the current carrying capacity. If using the cyclic ampacity to control the cable load, its transmission capacity can be improved greatly without any additional investment [2].

IEC 60853 standards have given the calculation methods of the cable cyclic ampacity factor and the cyclic ampacity [3,4], with condition that the conductor temperature will up to but not exceeding the maximum allowable cable insulation working temperature. In order to bring the transmission capacity of 10kV distributed cable lines into full apply, a three-core cable cyclic ampacity calculation software is developed and the cyclic ampacity experiments of direct buried cable are undertaken in this paper, and also the software calculations are used to do theoretical research. There are few articles about the cyclic in domestic now, but these experiments can provide some experiences and references for future related researches.

2. Experimental Study Content

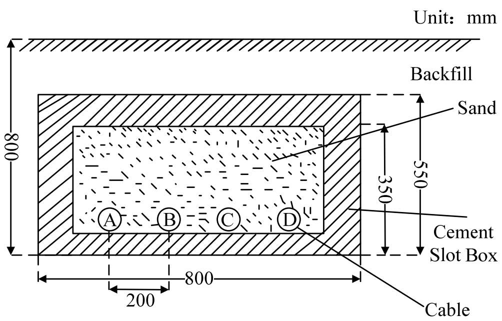
2.1. Test Object and Ground

Experiments are undertaken in Foshan experiment field, shown in **Figure 1(a)**. Cables are located in the cement tanks box filled with sand, which is buried in the soil, shown in **Figure 1(b)**. The depth of cable is 700 mm, the length of cable is 20 m and the cable is YJV22-8.7/ 15-3 × 240.

2.2. Selection of Daily Load Curve

According to Foshan residential, industrial, commercial and hybrid four typical load, this project select 10 lines to analyze the daily load factor, which is defined as formula (1) [5]. Considering the daily load curves in one month are almost the same, we select a typical load curve, the maximum one, in one month. 33 daily load curves, imported from Foshan Power Supply Bureau SCADA system of 33 months (from January 2009 to September 2011), are used to calculate the daily load factor.

(a) The experimental base in Foshan



(b) The sectional view of laying of the experimental cables

Figure 1. Schematic diagram of cable laying method.

$$LF = \frac{1}{I_{\max} \cdot \tau} \cdot \int_{t=0}^{\tau} I(t) \cdot dt \qquad (1)$$

For the load current is adjusted in every 15 minutes, each daily load curve data will have 96 data per day. Discretization of the formula (1) can be rewritten as:

$$LF = \frac{\sum_{1}^{96} I(t)}{I_{\max} \times 96} \qquad (2)$$

Typical daily load curves of LF 0.5, 0.7, 0.8, and 0.9 are selected to control the current applied in experiments. The red curve in **Figure 2** is the selected load with0.7 daily load factor.

2.3. The Direct Burial Experiment

Single-loop cyclic ampacity experiments of direct buried cable are carried out with the daily load factor 0.5, 0.7, 0.8, 0.9 and 1 (i.e. the continuous load) and four-loop cyclic ampacity experiments with 0.7 daily load factor.

During the experiment, cyclic current is loaded in the cables according to the selected load curves while recording the temperature of the cable conductor and skin by thermocouple. Adjust the peak current every day but keep the load curve shape till the conductor temperature is about 90℃(the highest permitted temperature of XLPE insulation) and get a named quasi static state, which is defined as the difference of the conductor temperature and peak current between the last two days are less than 2℃and 5% respectively. In this situation the peak current of the last cyclic is defined as the cyclic ampacity [6-10]. **Figure 2** shows the procedure of current, conductor temperature, the skin temperature and the surrounding soil temperature in the cyclic ampacity experiment. **Table 1** and **Table 2** show the results of cyclic ampacity experiments of the single-loop and four-loop.

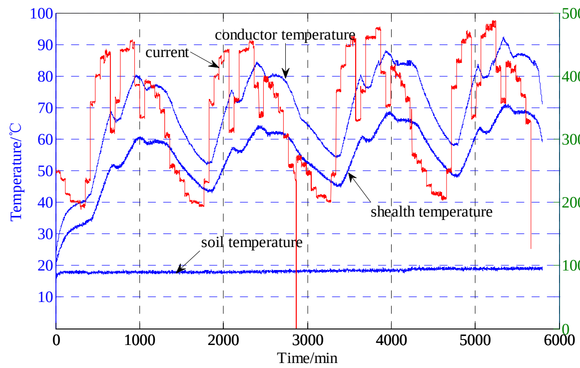


Figure 2. Graph of LF 0.7 single-loop direct buried cable cyclic ampacity experiment.

Table 1. Results of cyclic ampacity experiment of the single-loop cable.

LF	0.5	0.7	0.8	0.9	1
Cyclic ampacity /A	528.3	487.9	545.1	531.1	380
Maximum conductor temperature/℃	92.0	90.7	89.7	89.5	91.1
Maximum skin temperature/℃	73.7	73.5	72.4	72.4	81.7
Ambient temperature/℃	18.3	18.3	19.9	18.7	23.1

Table 2. Results of cyclic ampacity experiment of the four-loop cable.

LF	0.7	1
Cyclic ampacity /A	344.0	268.0
Maximum conductor temperature /℃	88.4	89.77
Maximum skin temperature /℃	80.4	84.3
Ambient temperature /℃	24.3	22.5

3. Comparison of the Experiment and Calculation

3.1. The Calculation of Cable Cyclic Ampacity

According to IEC60853 standard, cyclic ampacity is equal to cyclic ampacity factor M multiplied by the continuous ampacity [4].

$$M = \sqrt{\frac{1}{\sum_{i=0}^{5} Y_i \left[\frac{\theta_R(i+1)}{\theta_R(\infty)} - \frac{\theta_R(i)}{\theta_R(\infty)}\right] + \mu\left[1 - \frac{\theta_R(6)}{\theta_R(\infty)}\right]}} \quad (3)$$

where:

Y_i is the function of cyclic load factor; $\theta_R(i)$ is the temperature rise of i-th hour; $\theta_R(\infty)$ is the steady-state temperature rise of continuous current conductor; μ is the cyclic load-loss factor.

If the cyclic ampacity is used to control the cable load, the highest conductor temperature of cable will reach but not exceed 90℃, which is the allowed long-term working temperature of XLPE. Three-core cable cyclic ampacity calculation software has been developed according to IEC60853 standards.

3.2. Comparison of the Calculation and the Experiments of Cyclic Ampacity

The cyclic ampacity experiments of the single-loop and four-loop are calculated by the software developed in this paper, as shown in **Table 3** and **Table 4** respectively. As comparison, the experiment results are also show in **Table 3** and **Table 4**.

It can be seen from **Table 3** and **Table 4** the maximum error of the calculation and the experiment of the single-loop and four-loop are -3.6% and -0.2% respectively, showing the correctness of the calculation of the cable cyclic ampacity.

3.3. Comparison of the Calculation and Experiment of Cyclic Ampacity Factor M

The thermal resistance coefficients of surrounding media and the ambient temperatures are different in experiments. To get the cyclic ampacity factor M, the experiments are corrected from experiment condition to the standard condition, that is with 1.2 K•m/W thermal resistance coefficients of surrounding media and 30℃ ambient temperature.

By *the 10kV cable ampacity calculation guide*, the experimental are corrected to standard condition, and the results are shown in **Table 5** and **Table 6**. According to the results, calculated values and experimental values are about the same. The experiment value of cyclic ampacity factor is the ratio of experiment result of cyclic ampacity to continuous one. The cyclic ampacity factor could be calculated by the software. **Table 5** and **Table 6** shows cyclic ampacity factor of experiment and calculation.

Table 3. Cyclic ampacity experiments and the calculation of the single-loop cable.

LF	0.5	0.7	0.8	0.9	1
	experimental values / calculated values	experimental values / calculated values	experimental values / calculated values	experimental values / calculated values	experimental values / calculated values
Cyclic ampacity /A	528/535	488/487	545/563	531/512	380/371
Error	1.3%	-0.2%	3.3%	-3.6%	-2.4%

Table 4. Cyclic ampacity experiment and calculation of the four-loop cable.

LF0.7	single loop	four loops
Cyclic ampacity /A	experimental values / calculated values	Test values / calculated values
	488/487	344/343.5
Error	-0.2%	-0.1%

Table 5. Comparison results of the single-loop direct buried cable cyclic ampacity experiment under the standard condition.

LF	0.5	0.7	0.8	0.9	1
	experimental values / calculated values	experimental values / calculated values	experimental values / calculated values	experimental values / calculated values	experimental values / calculated values
Cyclic ampacity /A	612/621	536/554	517/528	506/495	439/462
M	1.39/1.34	1.22/1.20	1.18/1.14	1.15/1.07	1/1

Table 6. Comparison results of the four-loop direct buried cable cyclic ampacity experiment under the standard condition.

LF0.7		single loop	four loops
Cyclic ampacity /A	test values	536	417.4
	calculated values	554	405
M	test values	1.22	1.35
	calculated values	1.20	1.26

From **Table 5**, the M with 0.5, 0.7, 0.8, 0.9 daily load factors are 1.34, 1.20, 1.14, 1.07 respectively. That means, if a current with 0.7 daily load factor is applied to the single circuit cable, the peak value of the current can be up to 1.2 times continuous ampacity, and the highest conductor temperature is no more than 90℃, which means a lot for summer peak load period.

4. Study on the Influence Factors of Cyclic Ampacity

4.1. The Influence of the Daily Load Factor

It is shown in **Table 5** and **Table 6** that with the increase of the daily load factor, the cyclic ampacity is reducing but it is still bigger than the continuous ampacity. What's more, the cyclic ampacity factor M (>1) is reducing as well. That is to say if the cyclic ampacity is used to control the cable load, the transmission capacity of the cable can be improved greatly. And the smaller the daily load factor is, the greater the cable transmission capacity can be improved

4.2. The Influence of the Circuit Numbers

For limitation of the experiment condition, cyclic ampacity factors of multi circuits with different daily load factors are calculated by the verified software under the standard condition. The results are in **Figure 3**.

As is shown in **Figure 3**, when the daily load factors (LF) are the same, the cyclic ampacity factor M increase with the increase of circuit number. However, the increment of the cyclic ampacity factor has saturability. Circuit number has a significant influence on M when it changes from 1 to 6, and it has a small impact on M when circuit number changes from 6 to 12.

4.3. The Influence of Load Peak and its Shape

LF 0.5 and 0.8 load curves with diferrent shapes are shown in **Figure 4**. Curve *a* and *b* have the same shape, while their peak values are different. Curve *c* and *b* have different shapes, while their peak values are the same. The calculation of M is presented in **Table 7**.

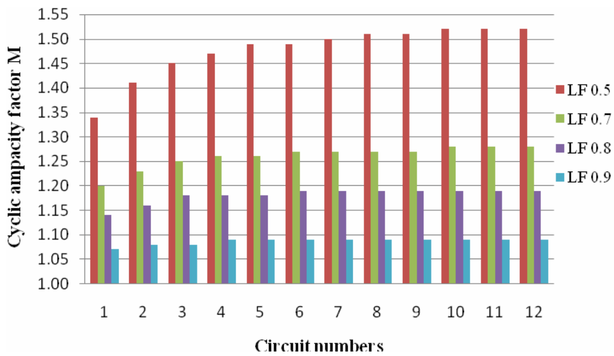
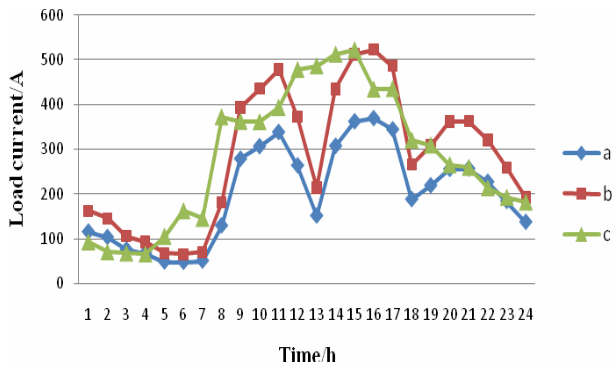
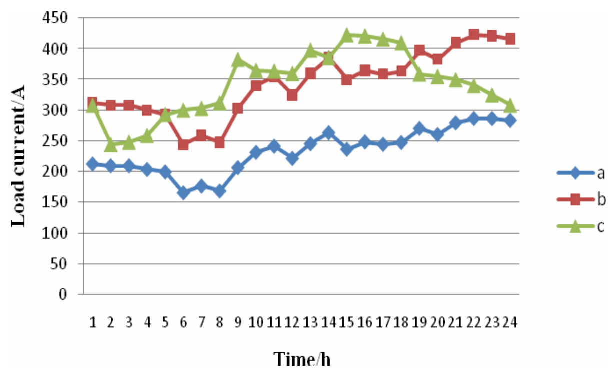


Figure 3. Relationship between cyclic ampacity factor M and circuit numbers.



(a) Different load curves of LF 0.5



(b) Different load curves of LF 0.8

Figure 4. Different load curves.

Table 7. The m of different load curves.

LF	0.5	0.8
Curve type	a/b/c	a/b/c
M	1.34	1.14

The calculation of M explains that M does not vary with the change of load curve shape with the same daily load factor. The result illustrates that M is related with LF, but not load curve shape and load.

5. Conclusions

The article approved the correction of this software based on the single-loop and four-loop cyclic ampacity experiments at different LF. The relationship between three-core power cable cyclic ampacity and LF is discussed by using the software. Conclusions are as followed:

1) The cable maximum current under cyclic load is larger than sustained load. Namely, cyclic ampactiy can increase the transmission capacity.

2) The cyclic ampacity factor is always no less than 1. The daily load factor lower, the cyclic ampacity factor larger.

3) Under the same daily load factor, the cyclic ampacity factor increase with the circuit number, but the improvement is not obvious when circuit number exceeds 6.

4) At the same LF, M does not vary with the change of load peak and its curve shape. The result illustrates M is related with LF, instead of load curve shape and load.

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