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The Reasonable Range of Life Cycle Utilization Rate of Distribution Network Equipment

LINHAO YE[1], ZHUANGLI HU[2], CANBING LI[1], (Senior Member, IEEE), YONGJUN ZHANG[3], SHIYAO JIANG[1], ZHIQIANG YANG[1], AND DI ZHANG[1]

[1]Development and Planning Department, China Southern Power Grid Company Ltd., Guangzhou 510663, China
[2]Foshan Power Supply Bureau, Guangdong Power Grid Company Ltd., Foshan 528000, China
[3]School of Electrical Power, South China University of Technology, Guangzhou 510641, China

Corresponding author: Canbing Li (lcb@hnu.edu.cn)

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ABSTRACT The utilization rate of power equipment plays a decisive role in the economic operation of power utilities. By determining the reasonable range of life cycle utilization rate of the distribution network equipment, it is of great significance to the management of the distribution network equipment. In this paper, the reasonable range of the life cycle utilization rate of distribution network equipment is determined. The life cycle utilization rate of distribution network equipment depends on the burden rate, load rate, and life expectancy rate, whose reasonable values are analyzed and exemplified, respectively. The optimal model of the burden rate in different conditions is established. The different load characteristic curves are also given by sorting out the load data. The calculation method of the life expectance rate is presented in this paper. The reasonable range of the life cycle utilization rate is finally obtained by defining the boundary condition of its composition. By setting the reasonable range of life cycle utilization rate of the distribution network equipment, power utilities can improve efficiency.

INDEX TERMS Distribution network, load rate, burden rate, life utilization rate.

I. INTRODUCTION

The utilization rate of distribution network equipment plays an essential role in the economic operation of power system [1]. By the end of 2015, the total assets of China's State Grid has reached about 3 trillion and 110 billion. The overseas total assets has reached to 40 billion US dollars. According to the analysis of China's domestic power transmission and distribution costs, in general, the depreciation cost of fixed assets accounts for the largest proportion of transmission and distribution costs, reaching 30%∼40% of the cost of power transmission and distribution. The improvement of the utilization rate of distribution network equipment not only can improve the economic efficiency of power utilities, but also can reduce energy consumption [2]–[4].

Life Cycle Assessment (LCA) refers to the compilation and evaluation of the input, output, and potential environmental impact of the life cycle of a product system [5]. The purpose of it is to find out the optimal strategy to eliminate the effects by tracking influential factors and evaluating them in a systematic way [6]. The life cycle utilization rate is used to study the utilization level of equipment throughout its life cycle and the equipment being evaluated is usually retired. LCA is widely used in the field of environment, energy and construction [7]–[9], for example, using biofuels to reduce the greenhouse gas emissions [10]. In [11] and [12], the application of the life cycle utilization rate in buildings' energy saving is described.

The life cycle utilization rate of distribution network equipment refers to the ratio of actual electricity generated or transmitted to the theoretical one by the equipment and it can be denoted by the product of load rate, burden rate and life expectancy rate [13]. Load rate reflects the utilization rate of electrical equipment from the perspective of demand side, while burden rate reflects the utilization rate of electrical equipment from the supply side. Life expectancy rate reflects the utilization rate of electrical equipment during its whole life cycle. Each evaluation index has its own reasonable range. In [14], the capacity factor was calculated and evaluated through the empirical models, and the values of the capacity factor in each model were obtained. In [15] and [16], an index model which is used to evaluate the total power supply capacity of distribution network was proposed, and the value interval of load rate and burden rate of distribution network were analyzed. The current range of life cycle utilization rate of equipment is not unified. By analyzing the burden rate, load rate and life expectancy rate respectively, the reasonable range of the life cycle utilization rate can be determined, and the utilization level of distribution network equipment can be obtained, which can provide references for the operation of the power system.

In this paper, the reasonable range of the life cycle utilization rate is determined through comprehensive analysis of the reasonable range of load rate, burden rate and life expectancy rate of distribution network equipment. The remainder of this paper is organized as follows: In section 2, the reasonable value of burden rate of transformers and distribution lines are given. The typical annual load curves and the value of load rate of different types of load are presented in section 3. In section 4, the life expectance rate of equipment is explored. The reasonable value interval of life cycle utilization rate is also estimated in section 5. In section 6, the practical application of life cycle utilization rate is presented through some case studies. Finally, the conclusion is presented in Section 7.

II. REASONABLE BURDEN RATE OF DISTRIBUTION NETWORK EQUIPMENT

A. REASONABLE BURDEN RATE OF FEEDER LINES

The burden rate of feeder lines is defined as the ratio of maximum burden to capacity. The reasonable burden rate of feeder lines mainly refers to the maximum burden that the equipment can withstand, with consideration of certain safety and reliability principles, grid structure, load characteristics and the change of load. These factors are mainly taken into account from the level of grid planning. In addition, the reasonable burden rate and the actual utilization level of feeder lines should meet the constraints of the economic operating range of various types of equipment to ensure the coordinative relationship between planning and operation. In general, the reasonable burden rate of feeder lines is smaller than the burden capacity limit of feeder lines.

In addition to the economic operating range of equipment, the reasonable burden rate of feeder lines depends on three factors which are shown as follows:

1) Safety criteria that the distribution network is required to satisfy;

2) Load characteristics;

3) The margin reserved for the development of the distribution network.

The reasonable burden rate of feeder lines can be studied from the influence of each factor.

In the case where the ‘‘N-x’’ safety principles are satisfied and the equipment can connect with large amount of objects, each object only needs to share little amount of burden in the event of failure while it can bear more amount of burden during normal operation, which means the reasonable burden rate of equipment is high. What's more, the system needs to provide more spare capacity and the reasonable burden rate of equipment will decrease with the value's increase of ‘‘x’’ in the ‘‘N-x’’ safety principles [17]–[19].

The relationship between the maximum burden rate and connection modes of medium voltage distribution lines is shown in Table 1 in the case where the ‘‘N-1’’ safety principle is satisfied.

The load fluctuates with time change due to the influence of load characteristics. The maximum load in the whole year only occurs in a short period of time. Therefore, the study on the reasonable burden rate of feeder lines should also change with time and load. The load rate describes the relationship between the average load of a period (such as a year) and the maximum load in the period (corresponding to a time section).This index can be used to determine the reasonable burden rate of feeder lines considering the annual average load and the maximum load.

$$\frac{B_{l-avg}}{B_{l-\max}} = \frac{L_{l-avg}}{L_{l-\max}} = \beta \tag{1}$$

where B_{l-avg} and $B_{l-\max}$ represent the reasonable burden rate of feeder lines considering the annual average load and the maximum load, respectively; L_{l-avg} and $L_{l-\max}$ represent the annual average load and the maximum load of distribution network, respectively; β represents the load rate.

Power supply capacity or utilization rate of the distribution network equipment tends to reserve a certain margin for the future load development. Obviously, the reserved margin will reflect the difference of development planning, economic growth rate and policy enforcement in different areas. Therefore, the reasonable burden rate of feeder lines will also be different.

$$B_n = \frac{B_0}{(1+\alpha)^n} \tag{2}$$

where B_0 and B_n represent the reasonable burden rate of feeder lines before and after considering the load development, respectively; α represents the regional load growth speed; n represents the time that the margin will be reserved, and its unit is year.

The reasonable burden rate of feeder lines should be given by the following equation based on the above factors:

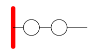
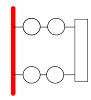
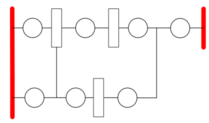
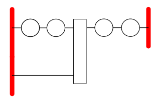
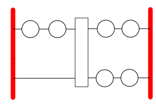
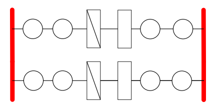
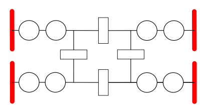
$$B = \frac{b_R \times \eta}{(1+\alpha)^n} \tag{3}$$

where B represents the actual reasonable burden rate of equipment; b_R represents the maximum burden rate of feeder lines only considering the reliability and the grid structure; η represents time coefficient which describes the parameters corresponding to the objects at different periods of time. The values of η are shown in equation 4.

$$\eta = \begin{cases} 1, & \text{When assessing the annual maximum load} \\ \beta, & \text{When assessing the annual average load} \end{cases} \tag{4}$$

The load can be summarized as four categories, which are office load, commercial load, residential load and industrial load respectively. The industrial load can be divided into ‘‘steady with no fluctuation’’, ‘‘single peak’’, ‘‘double peaks’’

TABLE 1. Connection modes and reasonable burden rate.

Connection modes	The average maximum burden rate of each line in the wiring group	Schematic diagrams
Single radiation wiring	Features: simple wiring; low investment; high burden rate of feeder lines (maximum value is 100%); low power supply reliability; the requirements of power transfer and supply in the event of failure or maintenance can't be met.	
"2-1" single ring network	Features: high power supply reliability; simple wiring; easy operation; the "N-1" safety principle can be satisfied; low burden rate of feeder lines (maximum value is 50%)	
"3-1" single ring network	Features: high power supply reliability; high burden rate of feeder lines (maximum value is 66.7%); the "N-1" safety principle can be satisfied.	
Two-supply-one-backup connection mode	Features: high power supply reliability; the "N-1" safety principle can be satisfied; high burden rate of feeder lines (maximum value is 66.7%).	
Three-supply-one-backup connection mode	Features: high power supply reliability; the "N-1" safety principle can be satisfied; high burden rate of feeder lines (maximum value is 75%).	
Double ring network (switch station)	Features: high power supply reliability (in the case where the utilization rate of feeder lines is 50%, the requirement of "N-1-1" can be satisfied); the maximum burden rate of feeder lines is 75%, in the case where the "N-1" safety principle is satisfied.	
Double ring network (2 independent single rings)	Features: high power supply reliability (in the case where the utilization rate of feeder lines is 50%, the requirement of "N-1-1" can be satisfied); the maximum burden rate of feeder lines is 75%, in the case where the "N-1" safety principle is satisfied.	

| represents the bus bar, ○ represents the burden, ▯ represents the tie switch, ⍂ represents the sectional switch and — represents the distribution lines.

TABLE 2. The reasonable burden rate of feeder lines.

Safety principles	Load rate	Load growth speed	Reserved time/year	The reasonable burden rate of feeder lines	
				Maximum load	Average load
N-1-1	0.35~0.5	5%~10%	1~2	48%~68%	24%~34%
N-1-1	0.35~0.5	5%~10%	2~3	43%~65%	22%~32%
N-1-1	0.35~0.5	5%~10%	3~4	41%~56%	21%~28%
N-1	0.35~0.5	5%~10%	1~2	48%~68%	24%~34%
N-1	0.35~0.5	5%~10%	2~3	43%~65%	22%~32%
N-1	0.35~0.5	5%~10%	3~4	41%~56%	21%~28%

and "three peaks". Different types of loads have different values of β. The margin of electrical equipment will be reserved and the time is generally 1~4 years. The reasonable burden rate of feeder lines can be calculated as shown in Table 2.

The lines should ensure safe and reliable power supply of distribution network when the load reaches its maximum value. In this paper, the burden rate when the feeder lines reach their maximum load is taken as the reasonable burden rate of feeder lines. As shown in Table 2, the range of the reasonable burden rate is 45% to 65%.

B. REASONABLE BURDEN RATE OF TRANSFORMERS

Considering different factors, power transformers have different reasonable burden rate including burden rate of minimum active power loss rate, minimum annual power loss rate, minimum annual operating cost rate, minimum total cost rate of payback period and minimum annual cost rate.

1) THE BURDEN RATE OF MINIMUM ACTIVE POWER LOSS RATE

The active power loss can be calculated as shown in equation 5.

$$\Delta P = P_0 + (\frac{S}{S_N})^2 P_k \tag{5}$$

where ΔP represents the active power loss, P_0 represents the no-load active power loss of the transformer, P_k represents the active power loss of rated burden of the transformer, S represents the burden of the transformer which needs to be calculated, S_N represents its rated capacity.

After that each term in equation 5 is divided by S, the active power loss of unit burden can be obtained. Its calculation formula is as follows:

$$\Delta p = \frac{\Delta P}{S} = \frac{P_0}{S} + \frac{S}{S_N^2} P_k \tag{6}$$

where Δp represents the active power loss of unit burden which is also called active power loss rate.

By using equation 6 to get the derivation of S and making it equal to 0, when the active power loss rate reaches its extreme value, the burden rate β_1 can be calculated as follows:

$$\frac{d\Delta p}{dS} = -\frac{P_0}{S^2} + \frac{P_k}{S_N^2} = 0 \tag{7}$$

$$\beta_1 = \frac{S}{S_N} = \sqrt{\frac{P_0}{P_k}} \tag{8}$$

In addition to the active power loss, the reactive power loss also exists because the reactive current caused by the transformers will get through the resistance in distribution network in the running of the transformers. The economic equivalent of reactive power K, which is the value of active power loss (kW) of per kVar reactive power and varies with the distance of power transmission, the times of voltage change and the condition of reactive power compensation, is introduced for easy calculation. The value of K of 35kV~110kV step-down transformers is 0.1 in the operation of distribution network.

The comprehensive loss of active power and reactive power of the transformers are calculated as follows:

$$\Delta P_\eta = P_0 + KQ_0 + (\frac{S}{S_N})^2 P_k + K(\frac{S}{S_N})^2 Q_k \tag{9}$$

$$Q_0 = \frac{I_0 S_N}{100} \tag{10}$$

$$Q_k = \frac{U_k S_N}{100} \tag{11}$$

where Q_0 represents the no-load reactive power loss of the transformer, Q_k represents the reactive power loss of short circuit of the transformer, I_0 represents the percentage of the idling current of the transformer and U_k represents the percentage of the impedance voltage of the transformer.

Therefore, in the case where the comprehensive loss rate of active power and reactive power is minimum, the burden rate can be calculated by applying the same principle. Its calculation formula is shown as follows:

$$\beta_2 = \frac{S}{S_N} = \sqrt{\frac{P_0 + KQ_0}{P_k + KQ_k}} \tag{12}$$

2) THE BURDEN RATE OF MINIMUM ANNUAL POWER LOSS RATE

The annual power loss of the transformer can be calculated as shown in equation 13:

$$\Delta E = T_0 P_0 + \tau(\frac{S}{S_N})^2 P_k \tag{13}$$

where ΔE represents the annual power loss of the transformer, T_0 represents the annual energization time of the transformer which is generally taken as 8760h and τ represents the time of annual active power loss of the transformer whose value is 3000h~4000h generally.

The annual power loss rate of the transformer can be calculated as follows:

$$\Delta e = \frac{\Delta E}{S} = \frac{T_0 P_0}{S} + \frac{\tau S}{S_N^2} P_k \tag{14}$$

where Δe represents the annual power loss rate of the transformer.

By using equation 14 to get the derivation of S and making it equal to 0, when the annual active power loss rate of the transformer reaches its extreme value, the burden rate β_3 can be calculated as follows:

$$\frac{d\Delta e}{dS} = -\frac{T_0 P_0}{S^2} + \frac{\tau}{S_N^2} P_k = 0 \tag{15}$$

$$\frac{d^2\Delta e}{dS^2} > 0 \tag{16}$$

$$\frac{I_0 P_0}{S^2} = \frac{\tau}{S_N^2} P_k \tag{17}$$

$$\beta_3 = \frac{S}{S_N} = \sqrt{\frac{T_0 P_0}{\tau P_k}} \tag{18}$$

β_3 represents the burden rate with the consideration of the minimum annual active power loss rate of the transformer.

In order to simplify the calculation, it is assumed that the hours of the annual active power loss are equal to the annual reactive power loss's (the fact is roughly the same). Similarly, in the case that the comprehensive loss rate of annual active power and reactive power of the transformer is minimum, the burden rate β_4 can be calculated as shown in equation 18:

$$\beta_4 = \sqrt{\frac{T_0(P_0 + KQ_0)}{\tau(P_k + KQ_k)}} \tag{19}$$

The burden rate in the case that the annual operating cost rate is minimum is the one that taking the sum of the cost of annual depreciation, maintenance, labor and power loss into account. According to the experience of engineering design, the initial investment is the largest in the case that the annual operating cost rate is minimum. Therefore, in the case that the

TABLE 3. The parameters of distribution transformers and the reasonable burden rate.

Distribution transformers	Rated capacity (kVA)	No-load loss (kW)	Loss of short circuit (kW)	Idling current	Impedance voltage	Reasonable burden rate β_4
1	30	0.13	0.63	2.3%	4%	67.34%
2	50	0.17	0.91	2%	4%	64.08%
3	63	0.2	1.09	1.9%	4%	63.51%
4	80	0.25	1.31	1.9%	4%	64.77%
5	100	0.29	1.58	1.8%	4%	63.52%
6	125	0.34	1.89	1.7%	4%	62.88%
7	160	0.4	2.31	1.6%	4%	61.69%
8	200	0.48	2.73	1.5%	4%	62.16%
9	250	0.56	3.2	1.4%	4%	62.00%
10	315	0.67	3.83	1.4%	4%	62.00%
11	400	0.8	4.52	1.3%	4%	62.35%
12	500	0.96	5.41	1.2%	4%	62.42%
13	630	1.2	6.2	1.1%	4.5%	65.14%
14	800	1.4	7.5	1%	4.5%	63.97%
15	1000	1.7	10.3	1%	4.5%	60.17%
16	1250	1.95	12	0.9%	4.5%	59.69%
17	1600	2.4	14.5	0.8%	4.5%	60.22%
18	630	1.03	7.29	1.1%	5.5%	55.68%
19	800	1.26	8.91	1%	5.5%	55.69%
20	1000	1.48	10.44	1%	5.5%	55.76%
21	1250	1.75	12.42	0.9%	5.5%	55.57%
22	1600	2.11	14.85	0.8%	5.5%	55.79%
23	2000	2.52	17.82	0.8%	5.5%	55.66%
24	2500	2.97	20.7	0.8%	5.5%	56.06%
25	3150	3.51	24.3	0.7%	5.5%	56.22%
26	4000	4.32	28.8	0.7%	5.5%	57.28%
27	5000	5.13	33.03	0.7%	5.5%	58.28%
28	6300	6.12	36.9	0.6%	5.5%	60.17%
29	200	0.48	3.06	1.5%	4%	58.72%
30	250	0.56	2.6	1.4%	4%	68.76%
31	315	0.67	4.32	1.4%	4%	58.39%
32	400	0.8	5.22	1.3%	4%	58.03%
33	500	0.96	6.21	1.2%	4%	58.27%
34	630	1.2	7.65	1.1%	4.5%	58.67%
35	800	1.4	9.36	1%	4.5%	57.29%
36	1000	1.7	10.98	1%	4.5%	58.28%
37	1250	1.95	13.05	0.9%	4.5%	57.25%
38	1600	2.4	15.57	0.8%	4.5%	58.12%

annual operating cost rate is minimum, using the burden rate as the design target has shortcomings.

The calculation method of the burden rate of minimum total cost rate during payback period is usually called static method, which compares the currency of different periods with each other without taking the time factor of the currency into account. It either does not consider the interest factor of currency loan, resulting that the currency of every country may be devalued.

The method of minimum annual cost rate is usually called dynamic method, which takes the time factor of the currency into account. However, most calculated values of the burden

TABLE 4. The load rate of different typical loads.

Typical annual load curves of different types of load	The calculation method of load rate	Load rate
Typical annual load curve of office load		20.1%
Typical annual load curve of commercial load		43.7%
Typical annual load curve of residential load		35.2%
Typical annual load curve of industrial load (steady with no fluctuation)	$\eta_l = \frac{\sum_{i=1}^{i=8760}(P_i \div P_{\max})}{8760}$	53.8%
Typical annual load curve of industrial load (single peak)		38.4%
Typical annual load curve of industrial load (double peaks)		33.3%
Typical annual load curve of industrial load (three peaks)		40.5%

where η_l is the load rate, P_i is the active power of the i^{th} hour of a year and $P_{\max}$ is the maximum active power of the year.

rate of minimum annual operating cost rate, minimum total cost rate during payback period and minimum annual cost rate are more than 1 actually. Therefore, they have no practical significance for power transformers.

In this paper, with the lowest loss rate as the principle, determine the reasonable load rate. When the transformers are running smoothly and no empty running exists, the equations that $T_0 = \tau$, $\beta_1 = \beta_3$ and $\beta_2 = \beta_4$ can be obtained. It is obviously that the annual power loss rate has more universal significance than the power loss rate. The power loss rate is a special case of the annual power loss rate. The annual power efficiency is the highest in the case that the annual power loss rate is minimum. Therefore, β_4, the burden rate in the case that the annual power loss rate is minimum, is used as the reasonable burden rate of transformers in this paper.

Take the parameters of 10kV distribution transformers in the literature of national standard GB6451-2008 named "Technical Parameters and Requirements of Three-Phase Oil-Immersed Power Transformers" as reference to calculate the reasonable burden rate of distribution transformers. The annual energization time of the transformer T_0 is generally taken as 8760h and the time of annual active power loss of the transformer τ is 4000h [20]. The different selected parameters of distribution transformers and their reasonable burden rate are shown in Table 3.

According to the parameters of national standard GB6451-2008 named "*Technical Parameters and Requirements od Three-Phase Oil-Immersed Power Transformers*" and [20], the calculated range of the reasonable burden rate of distribution transformers is 55.57%∼68.76%.

III. REASONABLE LOAD RATE OF DISTRIBUTION NETWORK EQUIPMENT

The classification of the load is conductive to the analysis of the load rate of distribution network equipment. The calculated results of load rate of different typical loads are shown in Table 4. It shows that the range of the load rate of distribution network equipment is 35%∼50%. The load rate mainly reflects the load characteristics. Therefore, the range of the reasonable load rate is considered to be 35%∼50% when analyzing the load rate of general equipment.

IV. REASONABLE LIFE UTILIZATION RATE OF DISTRIBUTION NETWORK EQUIPMENT

Malfunction rate λ of most equipment is the function changing with time and its typical curve is also called failure rate curve commonly known as bathtub curve [21]. If taking the failure rate of equipment as the reliability eigenvalue of products, the bathtub curve is a curve that using the time (t) as abscissa and using the failure rate as ordinate. In the medium and latter period of service life of equipment, the failure rate will increase rapidly with time and the malfunction will increase continuously due to the abrasion, aging and corrosion. High quality equipment begin to malfunction with loss in the final stage of life cycle of equipment.

After being put into service for a period of time, the malfunction rate of transformers will decrease and the failure rate will stay in a stable range with the exposed problems being handled and the operation staff's gradual familiarity and mastery to the transformers' performance. The duration is generally 15∼20 years [22]. In the latter period of service life of transformers, the malfunction rate will increase obviously due to the serious phenomenon of the insulation aging, the increase of the leakage current, the decrease of the insulation resistance, the change of composition of the dissolved gas in the oil and the increase of partial discharge.

The point P refers to the time that the equipment begins to malfunction with loss. But the malfunction rate is still in the allowable range. The malfunction rate of equipment will increase rapidly when the actual service life exceeds the design life. The point P refers to the reasonable service life of electrical equipment for reliable operation of equipment. According to the literature of national standard GB/T17468-1998 named "*Guidelines for Selection of Power Transformers*", the design life of distribution network equipment is generally 20 years. Therefore, the reasonable life utilization rate of point P can be calculated as shown in

TABLE 5. The reasonable value interval of the burden rate, load rate and life expectancy rate.

	Burden rate	Load rate	Life utilization rate
Lines	45%~65%	35%~50%	90%
Transformers	55.57%~68.76%	35%~50%	90%

TABLE 6. The reasonable value interval of the life cycle utilization rate.

	The reasonable value interval of the life cycle utilization rate	Low range	Good range	Excellent range
Lines	14.2%~29%	<5%	5%~14.2%	>14.2%
Transformers	17.5%~30.9%	<5%	5%~17.5%	>17.5%

TABLE 7. The life cycle utilization rate of transformers in Foshan.

Numbers	Capacity (kVA)	Actual power transformed during its service life (MVA·h)	Design life /year	Actual service life /year	The life cycle utilization rate
1	800	228.723	20	11	0.16%
2	250	589.320	20	12	1.35%
3	200	42.798	20	15	0.12%
4	800	4174.519	20	13	2.98%
5	500	535.562	20	17	0.61%
6	800	498.780	20	22	0.36%
7	630	53.623	15	7	0.06%
8	500	1401.099	15	24	2.13%
9	500	584.505	12	8	1.11%
10	500	123.215	12	7	0.23%
11	500	166.600	15	5	0.25%
12	400	1446.549	15	11	2.75%
13	250	8021.210	20	17	18.31%
14	500	18768.575	20	17	21.47%
15	160	4933.272	20	15	17.60%
16	315	11345.012	20	16	20.56%
17	400	15264.58	20	16	21.78%
18	160	8979.293	20	23	32.03%
19	50	472.384	12	10	8.99%
20	50	821.791	12	10	15.64%
21	30	492.527	12	16	15.62%
22	50	739.389	12	15	14.07%
23	200	368.147	12	6	1.75%
24	200	1451.147	12	10	6.90%
25	50	1329.235	12	13	25.29%

equation 19.

$$T_P = \frac{T_m + (\overline{T} + \underline{T})/2}{T_d} \tag{20}$$

where T_P represents the reasonable life utilization rate, T_m represents the required time before the failure rate stays in the stable range, $\overline{T}$ represents the upper limit of the time of the failure rate in the stable range, $\underline{T}$ represents the lower limit of the time of the failure rate in the stable range and T_d represents the design life of equipment.

$$T_P = \frac{0.5 + (15 + 20)/2}{20} = 90\% \tag{21}$$

TABLE 8. **The life cycle utilization rate of transformers in Yangjiang.**

Numbers	Capacity (kVA)	Actual power transformed during its service life (MVA·h)	Design life /year	Actual service life /year	The life cycle utilization rate
1	30	590.650	20	14	11.24%
2	20	297.060	20	11	8.48%
3	20	223.190	20	11	6.37%
4	20	449.240	20	11	12.82%
5	30	450.250	20	7	8.57%
6	20	251.470	20	15	7.18%
7	30	83.370	20	3	1.59%
8	30	1196.200	20	11	22.76%
9	160	1474.200	20	7	5.26%
10	30	380.940	20	11	7.25%
11	20	248.490	20	12	7.09%
12	125	60.466	20	2	0.28%
13	20	161.100	20	4	4.60%
14	30	603.650	20	13	11.48%
15	200	1347.000	20	4	3.84%
16	10	433.520	20	14	24.74%
17	30	651.670	20	13	12.40%
18	30	513.000	20	12	9.76%
19	80	1757.500	20	9	12.54%
20	30	1246.000	20	11	23.71%
21	50	473.000	20	7	5.40%
22	30	525.700	20	13	10.00%
23	400	697.000	20	7	0.99%
24	100	1894.000	20	15	10.81%
25	80	1608.000	20	11	11.47%
26	50	1370.700	20	16	15.65%
27	100	1608.000	20	12	9.18%
28	20	46.376	20	14	1.32%
29	30	67.717	20	14	1.29%
30	30	61.833	20	13	1.18%
31	30	70.067	20	16	1.33%
32	20	44.604	20	12	1.27%
33	30	52.835	20	11	1.01%
34	30	51.485	20	12	0.98%

V. THE REASONABLE VALUE INTERVAL OF THE LIFE CYCLE UTILIZATION RATE

The reasonable value interval of the burden rate, load rate and life utilization rate of distribution lines and transformers can be obtained from the comprehensive analysis of above sections as shown in Table 5.

By taking the work requirements of daily planning as references and combining with the boundary condition of the reasonable value interval of the burden rate, the burden rate of feeder lines which is less than 20% is defined as low burden rate, the burden rate in the range of 20%∼45% is defined as good burden rate and the one more than 45% is defined as excellent burden rate. Similarly, the burden rate of transformers which is less than 20% is defined as low burden rate, the burden rate between 20%∼55.57% is defined as good burden rate and the one more than 55.57% is defined as excellent burden rate.

According to the reliability management statistics of National Energy Administration, the average retired life of transformers is 15 years, the breakers' is 12 years, the

TABLE 9. The life cycle utilization rate of transformers in Shantou.

Numbers	Capacity (kVA)	Actual power transformed during its service life (MVA·h)	Design life /year	Actual service life /year	The life cycle utilization rate
1	100	953.688	20	18	5.44%
2	50	1579.650	20	19	18.03%
3	100	3878.096	20	17	22.14%
4	50	1472.205	20	18	16.81%
5	160	6001.198	20	14	21.41%
6	160	6680.982	20	20	23.83%
7	100	5415.780	20	18	30.91%
8	250	10294.778	20	18	23.50%
9	100	2906.508	20	10	16.59%
10	160	3736.495	20	16	13.33%
11	200	7853.534	20	10	22.41%

overhead lines' is 11 years and the electrical equipment' is about 12.7 years in China in recent years. The design life of distribution network equipment is generally 20 years. Therefore, the average life utilization rate can be calculated and its value is 63.5%. By taking the average life utilization rate of distribution network equipment in China as a reference and combining with the reasonable life utilization rate, the life utilization rate which is less than 63.5% is defined as low life utilization rate.

The load rate mainly reflects the load characteristics . Therefore, the range of the load rate can be considered to be 35%∼50% when analyzing the load rate of general equipment according to Table 6.

The reasonable value of the life cycle utilization rate is the product of the reasonable value of the burden rate, load rate and life expectancy rate of equipment. The reasonable range of life cycle utilization rate is calculated according to the boundary condition of low burden rate and low life expectancy rate, the value range of the load rate and the boundary condition of the reasonable value interval of the life cycle utilization rate of equipment.

There is individual equipment in distribution network whose life cycle utilization rate exceeds the reasonable value interval. And there is a certain contradiction between the utilization rate of equipment and the reliability of the power supply [23]. Although the equipment will be more fully utilized with the increase of the utilization rate, it is not recommended that the utilization rate of equipment exceeds the upper limit of the reasonable value interval in the case of ensuring the reliability of power supply.

VI. CASE STUDY

According to the index of life cycle utilization rate defined in previous sections, three typical cities of Yangjiang, Foshan and Shantou are taken as samples to analyze the case of the life cycle utilization rate of equipment in this paper. The calculation case and the specific situation of utilization rate are analyzed as follows:

A. THE LIFE CYCLE UTILIZATION RATE OF TRANSFORMERS

The life cycle utilization rate of some retired transformers in Foshan is shown in Table 7. It can be seen that 25 retired low voltage transformers in Foshan are taken as samples to analyze the life cycle utilization rate. According to the results of the utilization rate, the transformers of low life cycle utilization rate (less than 5%) in Foshan account for 52%.The transformers of good life cycle utilization rate (5%∼17.5%) account for 20%. The transformers of excellent life cycle utilization rate (more than 17.5%) account for 28%.

The life cycle utilization rate of parts of retired transformers in Yangjiang is shown in Table 8. It can be seen that 34 retired low voltage transformers in Yangjiang are taken as samples to analyze the life cycle utilization rate. According to the results of the utilization rate, the transformers of low life cycle utilization rate (less than 5%) in Yangjiang account for 35.3%. The transformers of good life cycle utilization rate (5%∼17.5%) account for 55.9%. The transformers of excellent life cycle utilization rate (more than 17.5%) account for 8.8%.

The life cycle utilization rate of parts of retired transformers in Shantou is shown in Table 9. 11 retired low voltage transformers in Shantou are taken as samples to analyze the life cycle utilization rate. According to the results of the utilization rate, the transformers of low life cycle utilization rate (less than 5%) in Shantou account for 0%. The transformers of good life cycle utilization rate (5%∼17.5%) account for 36.4%. The transformers of excellent life cycle utilization rate (more than 17.5%) account for 63.6%. The life cycle utilization rate of transformers in Shantou is slightly more than that the one in Foshan and Yangjiang.

The situation of the life cycle utilization rate of the selected retired transformers in Foshan, Yangjiang and Shantou is shown in Table 10. It can be seen that the transformers whose life cycle utilization rate is less than 5% in Foshan and Yangjiang account for 52% and 35.3% respectively and the utilization rate is low. In contrast, the transformers of good

TABLE 10. The life cycle utilization rate of transformers in Foshan, Yangjiang and Shantou.

The intervals of the utilization rate \ Cities	Foshan	Yangjiang	Shantou
[0, 5%]	52%	35.3%	0%
[5, 17.5%]	20%	55.9%	36.4%
[>17.5%]	28%	8.8%	63.6%

TABLE 11. The life cycle utilization rate of medium voltage lines.

Numbers	Capacity (kVA)	Actual transmission power during its service life (10MW·h)	Design life /year	Actual service life /year	The life cycle utilization rate
1	4650	4781.930	20	15	5.87%
2	4000	3734.496	20	15	5.33%
3	4000	2317.844	20	21	3.31%
4	4000	956.187	20	20	1.36%
5	4000	12231.308	20	23	17.45%
6	4940	30062.950	20	24	34.74%
7	4300	7527.264	20	18	9.99%
8	4700	14184.244	20	24	17.23%
9	3070	2968.241	20	24	5.52%
10	5300	10828.719	20	13	11.66%
11	4860	1499.050	20	7	1.76%
12	4860	1343.804	20	4	1.58%
13	4500	9272.580	20	9	11.76%
14	3300	20262.566	20	15	35.05%
15	5040	79.843	20	20	0.09%
16	5900	32.561	20	17	0.03%
17	3770	76.572	20	5	0.12%
18	3770	4964.458	20	16	7.52%
19	1400	71.447	20	12	0.29%
20	5100	4016.973	20	8	4.50%

and excellent life cycle utilization rate (more than 17.5%) in Shantou account for 100% and the utilization rate is high. It can be found from the data that the overall life cycle utilization rate of the transformers in Guangdong Province is low and there is room for improvement.

B. THE LIFE CYCLE UTILIZATION RATE OF MEDIUM VOLTAGE LINES

The data of the life cycle utilization rate of medium voltage lines in Foshan are taken as samples for calculation which is shown in Table 11. It can be seen that 20 retired medium voltage lines in Foshan are taken as samples to calculate and analyze the life cycle utilization rate. According to the results of the utilization rate, the medium voltage lines of low life cycle utilization rate(less than 5%) in Foshan account for 45%. The medium voltage lines of good life cycle utilization rate (5%∼14.2%) account for 35%. The medium voltage lines of excellent life cycle utilization rate (more than 14.2%) account for 20%.

VII. CONCLUSION

The utilization rate of distribution network is an important criterion to measure the economic operation of the power utilities, and the solutions to improve it effectively earns much attention of the power utilities. The reasonable value of the life cycle utilization rate can be obtained according to the product of the reasonable values of the burden rate, load rate and life utilization rate of distribution network. The reasonable range of life cycle utilization rate is calculated according to the boundary condition of low burden rate and low life utilization rate, the value range of the load rate and the boundary condition of the reasonable value interval of the life cycle utilization rate of equipment.

The life cycle utilization rate is applied in the actual calculation case in this paper. The life cycle utilization rate over 17.5% is excellent and less than 5% is low for low voltage transformers. The life cycle utilization rate over 14.2% is excellent and less than 5% is low for medium voltage lines. The value range of life cycle utilization rate is proved to be of practical significance. It provide references for power planning and improve the economy of the power system. When the life cycle utilization rate is lower than the reasonable value, the power utilities is reminded to analyze reasons and take measures.

In the future research work, we should further optimize the reasonable range of the life cycle utilization rate, further study the application of the life cycle utilization rate in the distribution network, and strive to improve the economic operation efficiency of the power enterprise.

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LINHAO YE was born in Guangzhou, Guangdong, China, in 1983. He received the M.S. degree from the South China University of Technology, Guangzhou, in 2009.

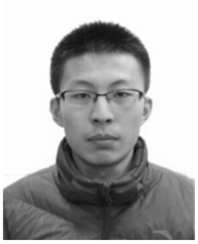
He is currently a Senior Engineer with the Planning and Development Department, China Southern Power Grid. His research interests include distribution network and smart grid planning.

ZHUANGLI HU was born in Yueyang, China. She received the B.E. and M.S. degrees in electrical engineering and automation from Hunan University, Changsha, China, in 2013 and 2016, respectively.

CANBING LI (M'06–SM'13) was born in Yiyang, Hunan, China, in 1979. He received the B.E. and Ph.D. degrees in electrical engineering from Tsinghua University, Beijing, China, in 2001 and 2006, respectively.

YONGJUN ZHANG received the Ph.D. degree in power system and its automation from the South China University of Technology, Guangzhou, China, in 2004. From 1995 to 2005, he was a Research Assistant with the School of Electric Power, South China University of Technology, where he was an Assistant Professor from 2005 to 2012, and he has been a Professor since 2012. He has authored five books and over 200 articles. His research interests include power system reactive power optimization, distributed generation control and optimization, voltage control, energy saving, and high-voltage direct current transmission.

SHIYAO JIANG was born in Changsha, Hunan, China, in 1994. She received the B.Sc. degree in electrical engineering and automation from the Changsha University of Science and Technology, Changsha, in 2016.



ZHIQIANG YANG was born in Ulanqab, Neimenggu, China, in 1994. He received the B.Sc. degree in electrical engineering and automation from Nanchang University, Nanchang, China, in 2017.

DI ZHANG was born in Nanyang, China. She received the B.E. degree in electric engineering and automation from the College of Physics and Electronic Engineering, Henan Normal University, Xinxiang, China, in 2014.