Analysis and classification of failures of capacitor banks at 110 kV substations of "Bashkirenergo" Ltd

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Abstract

In world practice, there is no unequivocal explanation and visual representation according to the life and reliability of the battery from static switching transients BSC-110, the type of the circuit breaker in BSC-110 and parameters of regime and network. This paper describes the experience of operating in the BSC-110 in Ltd "Bashkirenergo" and presents the calculation of reliability and probability of failure-free operation of capacitors BSC-110. It describes the effect of re-strike or re-ignition, and surges during switching BSC-110 on the life of capacitors.
Keywords: capacitor, circuit breaker, re-strikes, re-ignition, the probability of failure-free operation, the probability of failure, the mean time to failure, failure rate.

1 Introduction

When determining the life of some electrical equipment, the engineer shall be guided by operational experience, calculations, and most often norms of depreciation deductions for complete restoration.

At the same time it is very important to know the actual service life of electrical equipment and its dependence on the operation mode.

In this paper the focus is on the analysis of transients on the service life of electrical substation equipment when battery static condensers 110 kV (BSC-110) is switching.

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2 Operating experience of BSC-110 in Ltd "Bashkirenergo"

Analyzing the experience of operation of capacitors series КС1-0,66-20-1У1, КС-2-1,05-60-1У1, КЭК1-1,05-63-1У1 in Ltd "Bashkirenergo" substations "Subhankulovo", "Yazikovo" and "SibPP" accordingly. It can be noted that the main reasons for rejection, as noted in other papers [1], are still:

-loss of containment, insulation liquid flows in the weld seams;
-bulging capacitors;
-cracks in supporting insulators;
-blowing of fuses;
-internal failures;
-penetration of birds between the terminals of capacitors that leads to an explosion of cans.

For example, for the substation "Subhankulovo", from the moment of input in 1974 until 01.01.2011 has been damaged 1031 capacitor of BSC-110. The actual number of capacitors without defects is 1405 pieces, representing only 57.7% of the originally value. Main numbers of failures are defects associated with swelling of the tank of capacitors and internal breakdowns with the blowing of fuses, respectively. On this substation in average of 1% (24 pieces) capacitors from the total number damaged every year.

A graphical representation of average percentage distribution of failures in three substations Ltd "Bashkirenergo" is depicted in figure 1.

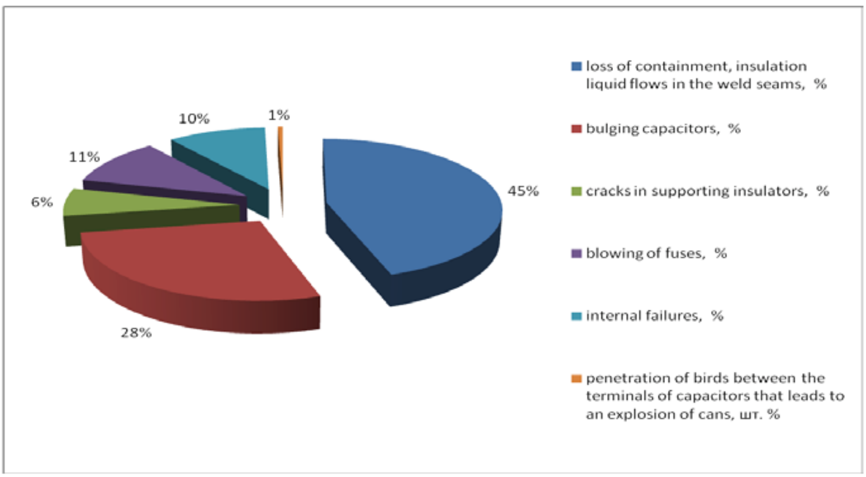

Figure 1: Chart of the average distribution of failures capacitors BSK-110 three substations Ltd "Bashkirenergo".

As shown in [2], when the voltage on the capacitor grows then the number of refusals increases and the time before the failures decreases. Also in the course of investigations is evident dependence of number of failures capacitors in batteries static capacitors 110 kV from the presence or absence of re-strikes and re-ignitions within interruption, as well as large surge of current when inclusions. In reality significant [3] voltage increase was not recorded, however, in substations, LTD "Bashkirenergo" fixed overvoltage and high-frequency current, caused by re-strike that led to the failure of the capacitors BSC-110. Thus, in the process of operation determined the effects of re-strike and re-ignition of the service life of capacitors BSC-110.

3 Reliability and failure-free operation probability capacitors BSC-110

The main quantitative indicators of the reliability of a capacitor of BSC-110 are the probability of non-failure operation and failure rate. Failure-free operation probability P(t) in the interval from 0 to t is the probability that a given interval of time or within a given operating time not arise from a failure of the product:

$$P(t\ ) = \int_0^t f(t)dt\ , \qquad (1)$$

where p(t) is the density of the probability distribution of an operating time to refusal.

Statistically P(t) is defined as the ratio of the number of the surviving elements of N-d during t to the total number of N elements of functioning at the moment of time t=0, where d is the number of faulty elements:

$$P(t) = 1 - dt(t)/N\ . \qquad (2)$$

Likely the opposite of an event is the probability of failure Q(t):

$$Q(t) = 1 - P(t)\ . \qquad (3)$$

Mean time to failure τ_{fal} statistically is defined as the average time element failures and is determined by the expression:

$$\tau_{fal} = \frac{1}{N}\sum_{i=1}^{N}\tau_i\ . \qquad (4)$$

For the studied substations Subhankulovo, Yazikovo, SibPP time between failures capacitors BSC-110 is 336 hours, 1272 hours and 3096 hours, respectively.

The failure rate of capacitors BSK-110 $\lambda(t)$ is the probability of failure per unit time after a given moment of time, provided that the failure to date by arose. Statistically $\lambda(t)$ is defined as the number of failures during the time interval from t to t+Δt, related to the number of items remaining to be faithful to the beginning of the time interval under consideration:

$$\lambda(t) \approx \frac{N(t) - N(t+\Delta t)}{\Delta t \cdot N(t)}, \tag{5}$$

where N(t) the number of defective items in a moment;
N(t+Δt)-the number of defective items in a moment t+Δt;

The intensity of failures on the studied objects was 26 per year or $2.96 \cdot 10^{-3}$ 1/h for substation “Subhankulovo”, 7 per year or $8 \cdot 10^{-4}$ 1/h for substation “Yazikovo”, 3 per year or $3.4 \cdot 10^{-4}$ 1/h for substation “SibPP”.

4 Calculation of re-strike or re-ignitions, as well as the surge of current during switching of BSC-110 for the lifetime of a capacitor

In this section, the method for calculating the lifetime of capacitors BSC-110 is shown. When determining life of paper-impregnated or film insulation capacitors, operating on alternating voltage [2].

Capacitor keeps its serviceability until its electric strength drops to the level at which the breakdown occurs, or until its tgδ reaches the value corresponding to the border of thermal stability, followed by a thermal breakdown.

The ageing of the dielectric has three forms:
-ionization, where it is destroyed arising by partial discharges (PD);
-thermal, its material is destructed mainly due to the processes of oxidation and is determined by the temperature dielectric;
-electrochemical, its aging has mainly electrochemical nature.

In practice, there are several forms of ageing at the same time. Under certain conditions, one of the forms can prevail over the other and determine resource capacitor.

Inrush current when you turn has an impact on the operation life of capacitors and other electrical equipment in the chain of BSC-110 mainly in heating and ionization form.

Dependence S[E(t), T(t)] expresses the share of the physical resource consumed per unit of time, and which is a rate of aging of the insulation or the intensity of the impact factors of aging from tension E(t) and temperature T(t) , which are in the General case functions of time, therefore, the link between physical resource isolation R and technical resource τ (hereinafter resource) is determined from the relation:

$$R = \int_0^{\tau} S\,[E(t), T(t)]\, dt. \tag{6}$$

We can accept that the lifetime value of S(E,T) remains unchanged, the resource

$$\tau = R / S(E,T). \tag{7}$$

The amount of material destroyed in a time unit S, or the rate of destruction of isolation, proportional to the power of the PD:

$$S = B \cdot P_{PD}, \tag{8}$$

where B is the amount of the material is destroyed by discharge with energy of 1 joule; P_{PD}- power of the PD.

For capacitors operating on alternating voltage U, the relationship between P_{PD} and voltage of frequency 50 Hz can be presented empirical dependence:

$$P_{PD} = A_{PD} \cdot U^{a_{PD}}, \tag{9}$$

where A_{PD} and a_{PD} permanent.

Substituting (9) into (8), and the latest in (7) in general, you can find the dependence of the capacitor life of tension E aging under the effect of the PD [4]:

$$\tau = R/(BP_{PD}) = A_1 \cdot U^{-a_{PD}} = A \cdot E^{-a_{PD}}, \tag{10}$$

where A and A_1 permanent.

In the general case, the velocity of chemical reactions increases with increasing temperature. Analytical resource dependence from temperature [4]:

$$\tau = \tau_0 \, exp\left[b_T \left(\frac{1}{T} - \frac{1}{T_0} \right) \right], \tag{11}$$

where τ and τ_0 resources at temperatures T and T_0 respectively;
b_T- an indicator of the degree of dependency τ from T.

To determine the decrease of a resource from exposure of re-strike or re-ignitions, and high-frequency surge of current during switching is proposed methodology stepped accounting tension, temperature and time, during the re-strike or re-ignition and high-frequency current, according to the formula:

$$\tau_{solve} = \sum_{i=1}^{n} \Delta t_i \left(E_i / E_{nom} \right)^a \cdot exp\left(-b \left(\frac{1}{T_i} - \frac{1}{T_{nom}} \right) \right), \tag{12}$$

where a - the indicator of the degree of dependence τ from Ei with re-strike or re-ignition;
b - an indicator of the degree of dependency τ from Ti at high-frequency throws current;
T_i temperature on i-th stage, ^oC;
T_{nom}- temperature under nominal conditions, ^oC;
E_i -tension on i-th stage, kV/m;
E_{nom} - tension at nominal conditions, kV/m;
τ_{solve} - estimated resource at a constant tension E_{nom}, hour;
Δt_i - the duration of the i-th stage at tension E_i and temperature T_i, hour;
Δt_n - time to failure at the last n-th stage when tension En [5], the hour.

For convenience of calculation should translate tension E_i to the voltage U_i and temperature T_i to the current I_i single capacitor with a corresponding change in the coefficients a and b. Thus, the formula becomes:

$$\tau_{solve} = \sum_{i=1}^{n} \Delta t_i \left(U_i / U_{nom}\right)^{K_{re-strike}} \cdot exp\left(-K_{surge} \cdot \left(\frac{1}{I_i} - \frac{1}{I_{nom}}\right)\right). \quad (13)$$

The task of further calculations and experimental data analysis is the determination of the coefficients of a re-strike and surge which allow determining the influence of the re-strikes and re-ignitions, and high-frequency current surge to the capacitors BSC-110.

To work out this problem you need to solve a system of equations for each substation (type condenser), based on the normative term of service products and the actual time worked:

$$\begin{cases} \tau_{req} = \tau_{fact_n} + \sum_{i=1}^{n} \Delta t_i \left(U_i / U_{nom}\right)^{K_{re-strike}} \cdot exp\left(-K_{surge} \cdot \left(\frac{1}{I_i} - \frac{1}{I_{nom}}\right)\right), \\ \tau_{req} = \tau_{fact_m} + \sum_{j=1}^{m} \Delta t_j \left(U_j / U_{nom}\right)^{K_{re-strike}} \cdot exp\left(-K_{surge} \cdot \left(\frac{1}{I_j} - \frac{1}{I_{nom}}\right)\right) \end{cases} \quad (14)$$

where variables with index i and j correspond to the parameters of capacitors, failed at different times for different periods n and m.

As a result of solving the system of equations (14) for three different substations, with three varieties of capacitors BSC-110 and high-voltage circuit breakers of 110 kV were received the following distribution of the roots of the system of equations (14) in figure 2.

It should be noted that the determination of the influence of the re-strike and re-ignitions, and high-frequency current surge to the capacitors in the structure of the BSC-110 was conducted solely on obviously defective capacitors.

On the basis of this distribution it is possible to speak about an average arithmetic value of the parameters $K_{re\text{-}strike}$ and K_{surge} equal 62,05 and 6085,82 respectively, according to the formula (13) equal the working for 1260 hours when one re-strike or re-ignition and 36 hours during high frequency current surge.

On the basis of available experience of operation of the BSC-110 to increase the probability of faultless work capacitors BSC-110 kV should be applied control switching jointly or without current-limiting reactor to minimize the influence of the processes occurring in re-strike and re-ignition, as well as high-frequency current surge.

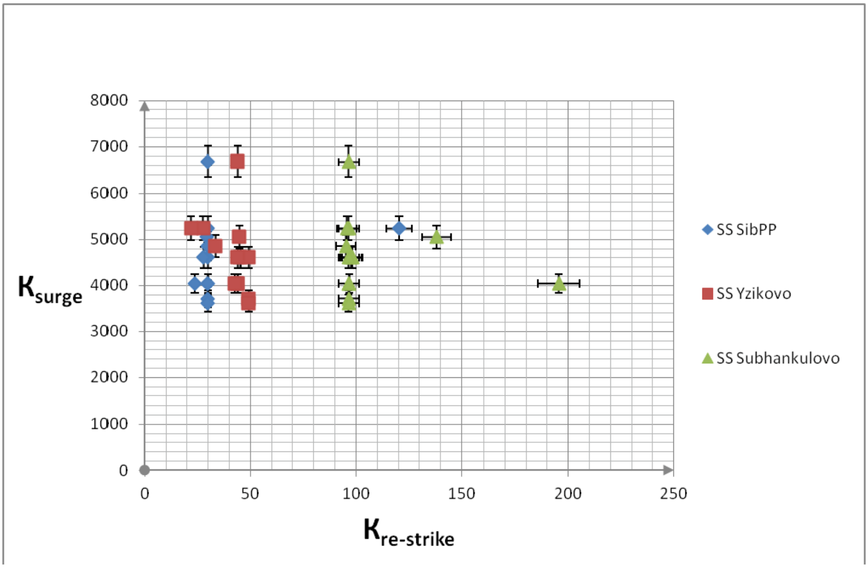

Figure 2: Distribution of values of the coefficients $K_{re\text{-}strike}$ and K_{surge}.

5 Conclusion

The analysis and classification of failures capacitors BSC-110 on three substations LTD. "Bashkirenergo" with the calculation of the probability of failure-free operation, the probability of failure, mean time to failure, failure rate, these parameters differ significantly from the norms.

The basic laws of capacitor failure BSC-110 are analysed.

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