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MODELING OF VACUUM CIRCUIT BREAKER DETERIORATION PROCESS

Y. Tolstoguzov, V. Krotenok
Gomel State Technical University, Republic of Belarus

Introduction

Ensuring reliable operation of power plants, substations and industrial power systems is largely determined by trouble-free operation of high voltage circuit breakers.

Circuit breakers is the main switching devices in electrical installations and are used to enable or disable the current circuits. A unique feature of circuit breakers is that they need to safely carry out their functions, being both in set and unset state, and at the same time to be constantly ready for instant execution of switching operations in all modes, including emergencies.

The increase in electrical equipment volumes, spent its lifecycle in spite of the significant increase in investment in the technical re-equipment of power objects over the past two years, the rate of wearing is still higher than rate of replacement by a new equipment. Such situation could lead in the next 10 years to further increase the level of depreciation of major assets of energy up to 70 % [1]. If it won't be stopped the electricity supply can lose its efficiency due to the occurrence of massive failures originated by the increase in depreciation of major assets.

Along with the physical deterioration of the electrical equipment there's another major process that we can see now and it's obsolescence of equipment. The average technical level of major power stations and substations curcuit breaker equipment corresponds to the equipment that has been used in the leading countries of the world 30 years ago [2]. The reasons of failures electrical networks 6 (10) kV are the aging structures and materials during the operation (18 %), the climatic effects above calculated values (19 %), storm surge (13 %), the disadvantages of operation (6 %), foreign exposure (16 %), and unknown causes of damage (28 %) [2].

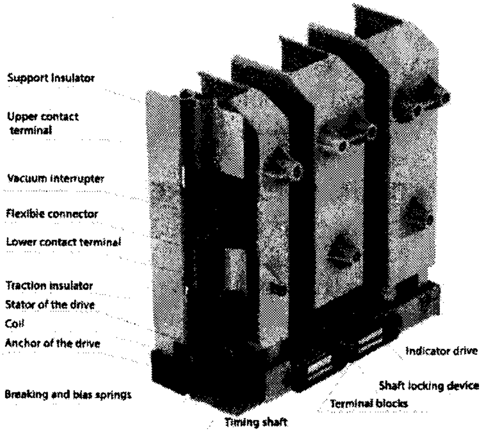

Fig. 1. Vacuum circuit breaker BB/TEL series

There is trends of development of high-voltage circuit breakers 6 – 35 [3] that shows a steady increase in the use of vacuum circuit breakers in the world. It is therefore important to understand how long already used and new vacuum circuit breakers will serve under certain conditions. This will help to calculate the ROI and depreciation of their use.

Main part

Given the diversity of possible causes of damage, the article attempts to create a mathematical model of the mechanical wear and which occurs only within the curcuit breaker. This article discusses the switch BB/TEL series in Fig. 1. Since most of the failure occurs in the bellows and related to defects that was added in the manufacturing processes, which are difficult to simulate with deterministic models, since they depend entirely on the production maturity, and can be estimated only a certain probability. Second place among the potential failure takes a problem with wear and aging of contacts' materials. For instance, during the passage of the arc between the contacts, in some places, where the arc is formed, it can be observed uneven heating and severe erosion of contacts, and when activating and deactivating big problem of contact wearing is a rivet from impact.

Next formula is going to be used in order to determine the wear of circuit breaker, which represents dependance of residual resource from the influence of various operational factors [4]:

$$R_{r}^{*} = R_{0r}^{*} - \sum_{j=1}^{K}\left(\int_{0}^{R_j^*} e^{\sum_{i_T=1}^{N_T}\frac{(X_{i_T j}^{*}-1)}{\Delta X_{i_T}^{*}} + \sum_{i_T=1}^{N_T}\frac{(X_{i_E j}^{*}-1)}{\Delta X_{i_E}^{*}} + \sum_{i_T=1}^{N_T}\frac{(X_{i_M j}^{*}-1)}{\Delta X_{i_M}^{*}} + \sum_{i_T=1}^{N_T}\frac{(X_{i_C j}^{*}-1)}{\Delta X_{i_C}^{*}}} dr - R_j^{*} \right) \quad (1)$$

Here we use next variables: $X_{i_T j}^{*}$, $X_{i_E j}^{*}$, $X_{i_M j}^{*}$, $X_{i_C j}^{*}$ values of i_T thermal, i_E electrical, i_M mechanical, i_C chemical factors; R_j^{*} – interval of operating time; K – the amount of consideration intervals.

To calculate the mechanical wear we need to calculate the value $X_{i_M j}^{*}$ and the deviation $\Delta X_{i_M}^{*}$. Thus, if we consider that other factors are within the normal range of use and does not contribute to wear significantly, then we can substitute the calculated values of the factor of mechanical wear and it will be expected mechanical residual life of circuit breaker.

In order to correctly simulate the complex processes of mechanical wear occurring under the stress of contacts it has been built the equation of motion of contacts depending on time in vacuum breaker with design BB/TEL. The technical passport for the curcuit breaker of this type contains the initial information that can be used to verify the formula. Chart of motion of the anchor per technical passport shown in Fig. 2.

Since the movable part of contact is subject of Newton's second law, its motion was represented with differential equation that combines the second derivative of the contact position with the forces that act on it:

$$\ddot{x} = \frac{\overrightarrow{F(x,t)}}{m} \qquad (2)$$

Taking into account that we have the following forces acting on the contact:

– The force of the electromagnet acting on the anchor;
– The force of the breaking spring compression;
– The force of the bias spring compression;
– The force of gravity;
– The force of friction.

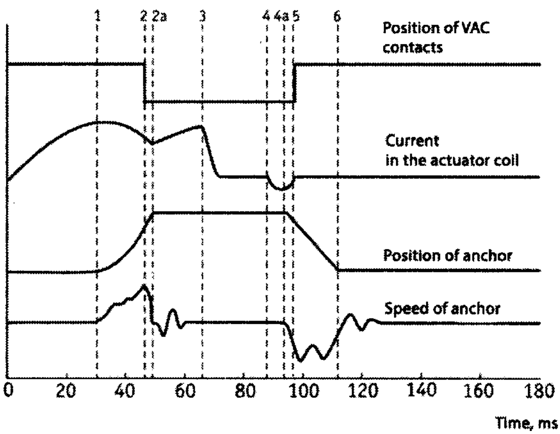

Fig. 2. Declared kinematic characteristics of the circuit breaker

We are interested in the movement of the anchor on which we can learn the characteristics of the impact of contacts, they are shown in Fig. 2. The interval is 1 – 2a represents switching on circuit breaker. The interval 4 – 6 is switching off.

Then, the resultant force can be described as follows:

$$\overrightarrow{F_{I}} - \overrightarrow{F_{el}} \div \overrightarrow{F_{br}} + \overrightarrow{F_{bias}} + \overrightarrow{F_{m}} + \overrightarrow{F_{fr}} \qquad (3)$$

Considering the mass of the movable part of contact with anchor as constant and knowing that the they moves along same axis, we can project the force vectors on the axis taking into account the typical switch installation:

$$F_{\Sigma} = F_{el}(t) - F_{br}(x) - F_{bias}(x) - F_{m} - F_{fr} \qquad (4)$$

Substituting the values of the forces we obtain the final formula of contact movement:

$$\ddot{x} = \frac{F_{el}(t) - k_{br}x - k_{bias}x - mg - \mu(F_{fr})}{m} \qquad (5)$$

Solving this equality using numerical analysis with classical Runge-Kutta method of fourth order accuracy with initial values of zero velocity and zero initial position, we find the force of contacts impact [5].

Equation damped oscillations after the initial contacts impact we can describe contacts rattling:

$$\ddot{x} + 2\zeta\omega_0\dot{x} + \omega_0 x = 0, \qquad (6)$$

where ω_0 *– initial impact moment speed,*

ζ *– factor directly depends on the hardness of the contacts*

By changing ω_0 after each passage of function throught 0 we can be achieve sufficiently accurate description of bounce. Chart of position of the moving contact, which is obtained by computer simulation [6] of the system from these equations is shown in Fig. 3.

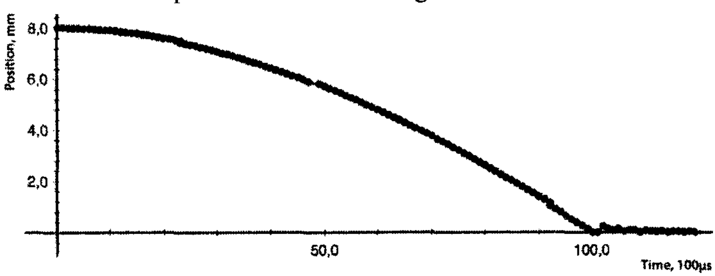

Fig. 3. Chart of moving contact position

However, impact and rattling characteristics of the contacts directly affect one of the coefficients in the formula of wear, namely the ratio of mechanical wear.

Thus, we can get a picture of mechanical wear of contacts by substituting the values of the coefficients in the original formula of the residual technical condition. Calculation of coefficients themselves was done by following formula:

$$k_i = v_i^2 / v_n^2 \qquad (7)$$

$$k_v = t_v^2 / t_n^2 \qquad (8)$$

Substituting the coefficients in the formula of residual life:

$$R_i = \log_n\left(1 + (n-1)\frac{A_{ki} - A_i}{A_{ki} - A_{Ni}}\right), \text{где } n \neq 1 \qquad (9)$$

It is proposed to evaluate the state of the circuit breaker for each i-th parameter using the function of residual resource R_i = f(A_{Ni}, A_{ki}, A_i), where I = 1, ..., m – number of measured parameters A_i of process that characterize its performance. The A_i parameter, which depends on k_i and k_v, and varies from an initial value to a final value, after which the curcuit breaker loses the ability to operate because of various reasons (physical, technical, etc.) [7].

As a result of computer modeling mechanical wear, we got chart which is shown on Fig. 4 for the initial values from the technical passport of circuit breaker of BB/TEL series.

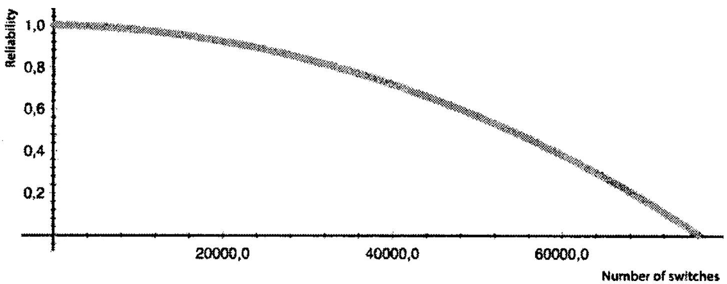

Fig. 4. Chart of probability of circuit breaker trouble-free work

Conclusion

The article describes the design of the vacuum breaker BB/TEL from the manufacturer "Tavrida Electric". This switch has excellent reliability and does not require repair prior to the expiration of the mechanical and electrical endurance. Simplicity of design allows us to describe these circuit breakers with sufficiently accurate mathematical model. Analysis of the results made in the article leads to the following conclusions:

– With the help of a described mathematical model we can found rates of mechanical wear and using specified formulas we can estimate the residual technical condition of equipment to calculate the time that circuit breaker can work, and the probability of failure-free operation at a certain stage of operationing. Dispersion of deviation from results the specified model gives from the experimental data is sufficiently small, and thus specified mathematical model can be used to assess mechanical wear.

– Such results can be used to calculate the economic benefits of replacing or calculate probable losses, if the switch is planned to be used more than the guaranteed service life.

– The model is described in an article suitable for many different types of vacuum circuit breakers which have similar construction. However, it should be understood that in case of switching to the characteristics highly varied from specified in the article the probability of error can be large and accuracy of model won't be any close.

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АДРОННЫЕ РАСПАДЫ ТЯЖЕЛОГО ЛЕПТОНА

Е. З. Авакян, С. Л. Авакян
Гомельский государственный технический университет
имени П. О. Сухого, Беларусь
E-mail: avakyan@tut.by

С момента открытия в 1975 году τ-лептон представляет собой важнейший инструмент для проверки фундаментальных аспектов электрослабого взаимодействия. В частности, в связи с тем, что масса τ- лептона велика, кинематически допустимыми являются адронные распады, а именно распады в нестранные и странные мезоны. Это позволяет дополнительно изучать как явления, связанные с сильным взаимодействием, так и явления, связанные со слабым взаимодействием. В отличии от хорошо известного процесса $e^+e^- \to \gamma$ адроны, который позволяет судить лишь о электромагнитном векторном токе, полулептонные распады τ-лептона дают возможность изучать как векторные, так и аксиальные токи.

В настоящее время экспериментальное изучение распадов тяжелого лептона ведется несколькими группами [1], [2]. Теоретическое изучение взаимодействий τ- лептона проводилось в различных подходах, обзор которых имеется в [3], [4].

Аналитическое выражение для ширины распада -лептона в легкие адроны содержит спектральные функции, явный вид которых зависит от выбранной модели «сильных» и «слабых» взаимодействий лептонов и кварков. И это, естественно, открывает большие перспективы исследований за рамками Стандартной Модели, что является, на сегодняшний день, одной из актуальнейших задач физики высоких энергий.

Особый интерес представляет изучение распадов, в конечных состояниях которых присутствуют псевдоскалярные мезоны.