V. M. Kytin, Dc. Sc. (Eng.), Prof.; O. E. Rybanenko, Cand. Sc. (Eng.); S. V. Mysenko

THE EXPERIENCE OF INTRODUCTION AND RELIABILITY SUPPORT OF SULPHUR HEXAFLUORIDE CIRCUIT BREAKERS IN OPERATION CONDITIONS

The paper considers the results of the analysis, performed after introduction of sulphur hexafluoride switches at the enterprises of South-West Energy System (SWES) and improvement of methods and means of technical diagnostics of high-voltage switches in operation conditions.

Key words: *high voltage switch, introduction, diagnostics.*

Introduction

Reliability of electric energy systems (EES) greatly depends on the methods and means of failures localization and elimination, restoration of normal operation mode. High-voltage switches (HVS) along with other equipment are referred to such means, one of the purposes of HVS is disconnection of faulty equipment and localization of short-circuit currents.

A great number of switches, used in energy systems of Ukraine, have been in operation for more than 25 years, this exceeds their standard service life. Nowadays enterprises of energy sector of national economy face the problem of providing reliable operation of such outdated equipment. Solution of this problem assumes several ways, for instance, planned and not stipulated in the plan reparations. Another way – it is replacement of the outdated equipment by new one.

Peculiarities of high-voltage switches choice

The problem of choosing new switch is not a simple one. There exists a great number of various types, constructions and manufacturers of switches (Fig. 1), that makes the choice of switches rather complicated , especially, if there is little experience of their operation. For instance, nowadays sulphur hexafluoride circuit breakers are manufactured for 35 kV, vacuum switches are manufactured for 110 kV, but the experience of such switches operation is far less, as compared with oil and air or sulphur hexafluoride circuit breakers, manufactured for 110 kV and vacuum switches – for 35 kV.

Taking the decision, regarding the type and manufacturer of new high-voltage switch (HVS), to be installed instead of outdated switch, not only basic parameters of new and outdated switches (for instance, rated voltage, maximum operating voltage, rated current, rated interrupting current, requirements, regarding electric stability and switching ability, steady leakage short-circuit current, resource by mechanical stability of cycles at C-t-D, requirements to construction, manufacturing and materials, technical characteristics of the drives, amount of closing and disconnecting electromagnets, completeness of the delivery, reliability requirements [1]), and peculiarities of their utilization on the place of operation (for instance, possibility of exciting current disconnection, taking into account starting current with minor limiting voltage without formation of dangerous over voltages, seismic stability of the region of installation, influence of climatic factors, etc.).

Also it should be taken into account connection and disconnection operations intervals, their intensity, because it is very important for the selection of generator or linear switches since mechanical resistance of vacuum switch is greater than that of sulphur hexafluoride circuit breaker. Cost indicators influence greatly the choice of switches in the range of voltages 6 – 35 KV, are installed of the lines of such classes of voltages than on the lines of higher voltages (110 kV).

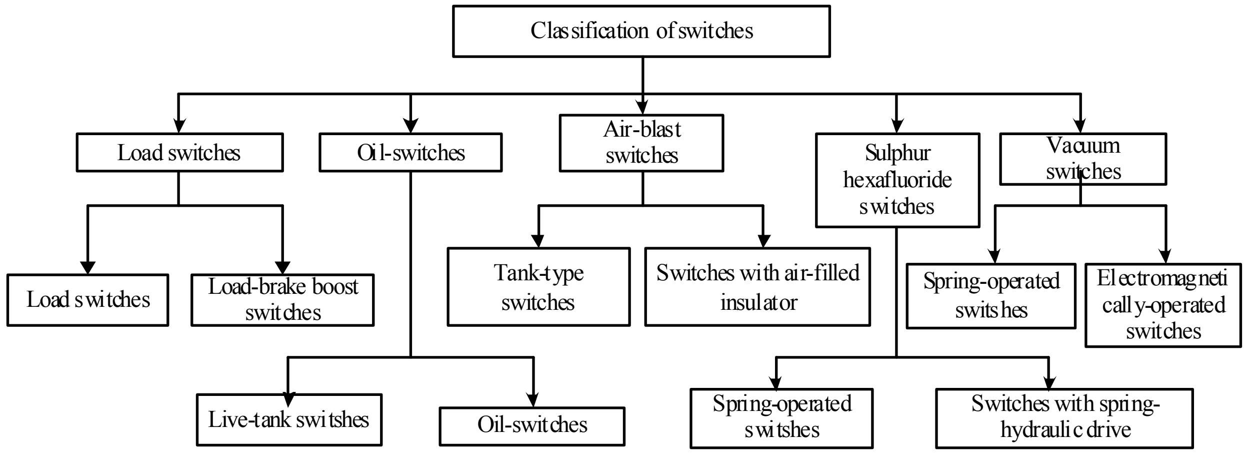

Fig. 1. Classification of switches

Study of switches cost and their repairs changes during their operation

The research, carried out (Table. 1, Table. 2, Table. 3) allowed to construct (Fig. 2) the dependences of new air and sulphur hexafluoride high voltage switches cost(C), installed in SWEES, on the year of manufacture (M), and dependences of expenses for their reparation on the year of their operation. To reduce the impact of inflation on the cost of switches and reparations during the considered period, this cost is determined relatively the cost of electric energy, sold by regional utility companies for the consumers of the first category by the expression (1). The initial point of coordinates corresponds to the year 1985.

$$B_{ut.} = \frac{B_{sw.}}{B_{el.}}, \tag{1}$$

where $B_{sw.}$ – is the cost of the switch, $B_{el.}$ – is the cost of electric energy for the consumers of the first category.

Table 1

Results of cost investigation of sulphur hexafluoride circuit breakers(per years)

Year	2008	2009	2010	2011	2012
Cost of sulphur hexafluoride circuit breaker rated for 110 kV, Hrs	181546	212850	232306	275104	326505
Cost of electric energy, Hrs	0.4046	0.5231	0.5678	0.6896	0.8377
Relative cost of sulphur hexafluoride circuit breaker, rated for 110 kV, Hrs	$4.4 \cdot 10^6$	$4.2 \cdot 10^6$	$4.1 \cdot 10^6$	$4.0 \cdot 10^6$	$3.9 \cdot 10^6$

The study of air switches cost change showed (Table 2): the cost of air switch of BBW-110 type in 1985 was 32 000,0 Rubs., in 1994 – 98 400,0 Rubs., in 2000 – 4 150 000,0 Rubs. [5, 6, 7].

Table 2

Results of cost investigation of sulphur hexafluoride circuit breakers in relative units (per years)

Year	1985	1994	2000
Cost of air circuit breaker, rated for 110 KV, r. u.	$3.0 \cdot 10^6$	$2.6 \cdot 10^6$	$2.0 \cdot 10^6$

Curves 1 and 4 (Fig. 2), correspondingly, show the dependence of relative costs change of new air and SF_6 circuit breakers on the year of manufacture. These dependences are described by the expression (2):

$$C = \frac{C_{r.u.}}{T_{yr.}}, \quad (2)$$

where $C_{r.u.}$. – is the cost of the circuit breaker in relative units, $T_{yr..}$ – is the year of account.

Curve 2 (Fig. 2) shows the regularity of relative cost change of air switch (AS) during operation, taking into account expenses for current and complete repairs both of switches and the equipment for compressed air preparation. Curve 3 (Fig. 2) shows the dependence of SF_6 circuit breaker cost growth during operation, taking into account the growth of total costs for technical maintenance and expenses for buying the equipment, needed for the work with sulphur hexafluoride gas.

Table 3

Results cost investigation of complete repairs per years

Year	2008	2009	2010	2011	2012
Complete repairs cost of B-110 kV switches, Hrs	19000	26200	22400	27200	27300
Complete repairs cost of the equipment for compressed air preparation, Hrs	36000	37000	38000	41000	42400

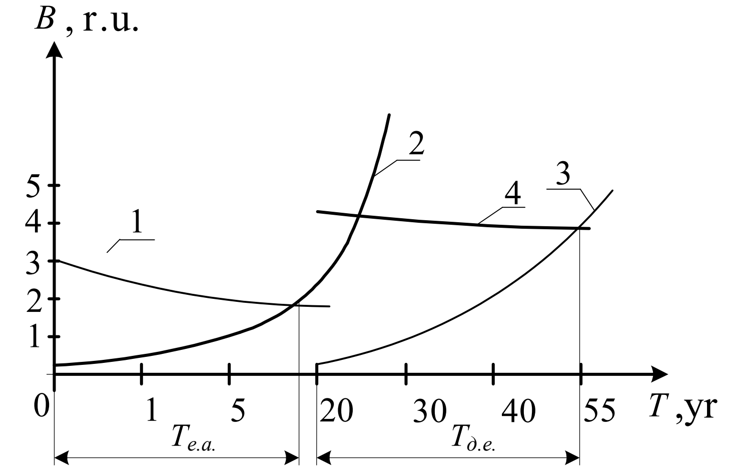

Fig. 2. Dependence of cost change of air and sulphur hexafluoride circuit breakers in the process of operation

The analysis of the dependences obtained, allowed to reveal the trends of growth of relative cost of repairs and drop of relative cost of new switches. Points of crossing of curves 1 and 2, 3 and 4 certify non-expediency to continue operation of air and SF_6 circuit breakers, correspondingly, if financial resources, spent on complete and current reparations exceed the cost of the new switch, that is stipulated by the drop of switches cost as a result of the improvement of manufacturing of the already developed constructions. It is seen from Fig. 2 that the predicted expedient term of SF_6 circuit breakers operation ($T_{exp.}$) exceeds this index for air switches $T_{e.a.}$, and that is why, the installation of new SF_6 circuit breakers is justified.

One of the most promising high-voltage circuit breakers are SF_6 circuit breakers, in which the arc is blown out more efficiently as compared with compressed air or oil. Taking into account problems regarding the prolongation of service life of oil and air switches, these switches in recent years are replaced by SF_6 circuit breakers. Nowadays the stock of SF_6 circuit breakers considerably increased at the expense of foreign switches of various constructions and manufacturers.

Mathematical model of air and oil switches replacement in SWEES

Table 4 contains the information regarding the replacement of outdated switches in south-west electric energy system.

Table 4

Results of study of sulphur hexafluoride circuit breakers integration

	1	2	3	4	5	6	7	8	9	10	11	12
Year	1998	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Quantity, pieces	2	2	6	3	2	1	5	15	3	8	7	7

The dynamics of replacement (amount of replaced switches during one year N, pieces) of oil and air switches, rated for 110 – 750 kV for SF_6 circuit breakers in South-West Electric Energy System (accounting year – A,yr) is shown in Fig. 3.

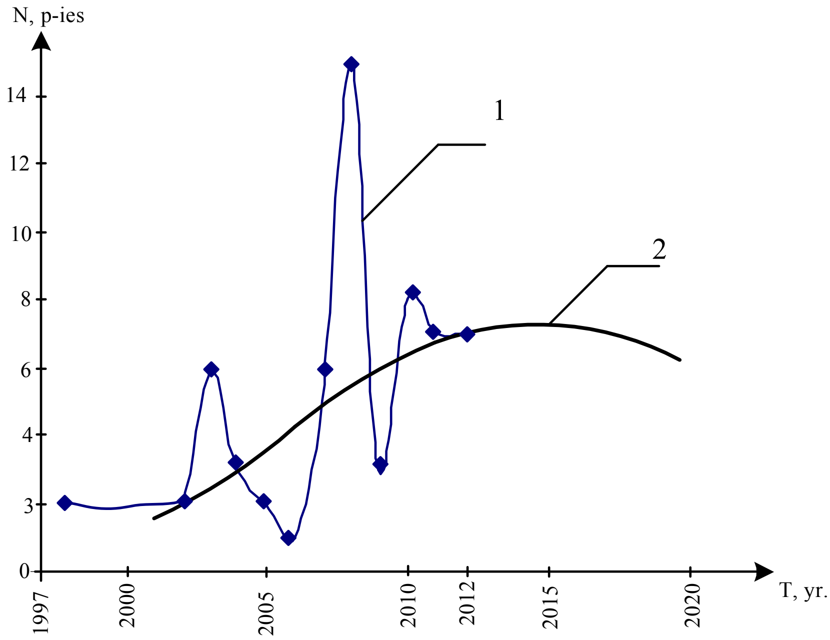

Fig. 3. Dependence of the quantity of installed switches on the year of mounting or putting into operation in SWEES

Fig. 3 shows: 1 – dependence of the amount of air and oil switches, rated for 110 – 750 kV to be replaced by SF_6 circuit breakers on the year of replacement from 1998 till 2012, 2 – dependence of predicted quantity of air and oil switches, rated for 110 – 750 kV to be replaced by SF_6 circuit breakers, on the year of replacement from 1998 till 2017, based on the contract between the company ABB and State Enterprise National Energy Company Ukrenergo, the dependence is constructed applying mathematic model of the process of high voltage switches introduction in SWEES (2), that was obtained by means of «Curve Expert» software.

$$N = \frac{k}{a_1 + a_2 \cdot k + a_3 \cdot k^{0,5}} = \frac{k}{47977475 + 23878{,}229 \cdot k - 2140663{,}7 \cdot \sqrt{k}}, \tag{3}$$

where N – is the amount of switches, k – is the year of installation, coefficients: a_1 = 47977475 (year), a_2 = 23878.229 (r.u.), a_3 = 2149663.7 (year^{0,5}).

Nowadays 54 SF_6 circuit breakers of ABB, AREVA, Siemens, Alstom types are installed at the substations of SWEES. The process of outdated switches replacement by new SF_6 circuit breakers, started in 1998, that is why, certified service life of certain switches will expire prior to realization of current reparation. SF_6 circuit breakers, put into operation less than one year, are available at SWEES. Small experience is available regarding operation of both SF_6 circuit breakers, expired their service life before the first complete reparation, and those switches of new constructions, put into operation not long ago. That is why, the problem of SF_6 circuit breakers technical state monitoring remains very actual. Accumulated experience of oil, air, SF_6 and vacuum switches certifies that their failures in greater part of cases are connected with faults of drives and arc chutes [2]. Hence, the existing means of technical diagnostics must be improved to reveal failures of various types of switches at early stages [3].

The analysis of high-voltage switches failures was carried out at open-joint-stock company «STC Electroenergetica» [1]. In the period of 1997 – 2007 years 62 failures of SF_6 circuit breakers (in Russia) were recorded. The majority of failures is connected with faults in switching – off blocks. Among these failures 7 faults of heating devices of Siemens type switches were registered, three faults of ABB LTB switches due to the damage of pressure indication devices, short-circuiting of secondary circuits of PLK-222 drive, faults of heating devices, one fault due to deformation of brass followers, accompanying contacts block (ACB) and other types of faults. The break of glass-epoxy traction on 110 kV circuit breaker, burning of disconnection electromagnets were recorded.

For instance, in 2006 failures (blocking of control circuits) of SF_6 tank circuit breakers, rated for 110 – 500 kV, manufactured by ABB and AREVA were registered due to non-sufficient capacity and low reliability of heating devices of tanks, drawbacks of pressure (density) control system of SF_6 gas at the temperature of the environment – 41 ^{0}C and lower.

Improvement of high voltage switches diagnostics

One of the ways to improve the quality of high voltage switches (HVS) diagnostics is the improvement of existing methods and diagnostic devices, realizing these methods, that widely use the possibilities of microprocessing elements, systems and complexes. For instance, speed characteristics which control modern microprocessing diagnostic systems are rather informative parameters of high voltage switches.

At SF_6 circuit breakers, speed characteristics can be determined by means of sensor of angular ДП21 and linear ДП11 displacement. However, determination of speed characteristics for SF_6 circuit breakers of various manufacturers is limited by constructive peculiarities of these or similar sensor location. That is why, improvement of methods and control means of speed characteristics for SF_6 circuit breakers in operation conditions is very important problem.

One of the ways of this problem solution is the control of test signal current of high frequency (3), that flows between switch contacts (Fig. 4).

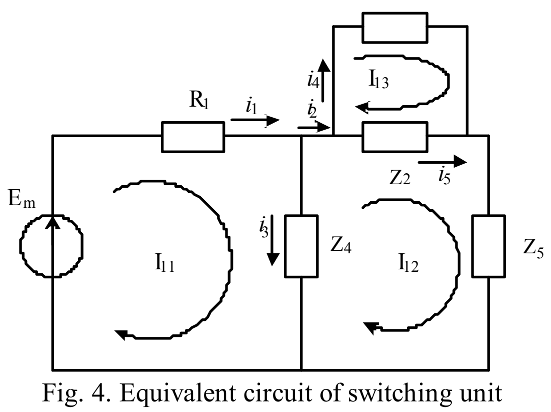

Fig. 4. Equivalent circuit of switching unit

Electromotive force (EMF) of test signal source:

$$E(t)=E_m \cdot sin\ (\omega \cdot t),$$

where ω – is angular velocity, t – is time, E_m – is amplitude value of e.m.f. of supply source.

According to Fig. 4, by means of contour currents method, we compose the system of equations

(4)

$$\begin{cases} i_1(t) = i_2(t) + i_3(t) \\ i_2(t) = i_3(t) + i_4(t) \\ I_{11}(t)\cdot(z_1 + z_4) - I_{12}(t)\cdot z_4 = E(t) \\ -I_{11}(t)\cdot z_4 + I_{12}(t)(z_4 + z_2 + z_5) = 0 \\ -I_{12}(t)\cdot z_2 + I_{13}(t)(z_2 + z_3) = 0 \end{cases}, \tag{4}$$

where i_1, i_2, i_3, i_4 – are currents in branches, and I_{11}, I_{12}, I_{13} – are currents in contours. By means of operational methods test signal current, flowing across active resistance R_1 of the sensor is found from the expression (5)

$$i(t) = \frac{U}{\dfrac{A\cdot B}{C} + R_1}, \tag{5}$$

where U – is the voltage of test signal source, $A = \left(\dfrac{R_2\cdot R_3}{R_2 + R_3 - i\cdot\omega\cdot R_2\cdot R_3\cdot(C_2 + C_3)} + \dfrac{R_5}{1 - i\cdot\omega\cdot R_5\cdot C_5}\right)$ $B = \left(\dfrac{R_4}{1 - i\cdot\omega\cdot R_4\cdot C_4}\right)$

$C = \left(\dfrac{R_2\cdot R_3}{R_2 + R_3 - i\cdot\omega\cdot R_2\cdot R_3\cdot(C_2 + C_3)} + \dfrac{R_5}{1 - i\cdot\omega\cdot R_5\cdot C_5}\right) + \left(\dfrac{R_4}{1 - i\cdot\omega\cdot R_4\cdot C_4}\right)$, R_1 – is an active resistance of the sensor, connected in series to test signal source, Z_2 – is the impedance between the contacts of the are chutes, consisting of capacitive impedance X_2 (resistance of capacitance C_2) and active R_2 (resistance of insulation between contacts) resistances, Z_3 – is the impedance of contacts relatively porcelain insulation for air and SF_6 switches, which consists of capacitive impedance X_3 (resistance of capacitance C_3) and active R_3 (serially connected two active resistances and serially connected two capacitive impedances) resistances, Z_4 and Z_5 – are impedances of moving and fixed contacts relatively grounded parts of the switch, consisting of capacitive impedances X_4, X_5 (resistances of capacitances C_4, C_5) and active R_4, R_5 (R_4, C_4 – resistance and capacitance of fixed contact insulation relatively grounded parts of the switch) resistances.

Record of this current value at various frequencies allows to increase the accuracy of control of switch drive state and arc-chutes [4].

Conclusions

Nowadays many high-voltage switches (HVS), are in operation for more than 25 years and must be replaced. Manufacturers propose a wide range of high voltage switches, but Ukrainian specialists do not have much experience in the sphere of their operation. That makes the choice for replacement rather difficult.

In order to increase the reliability of switches operation it is necessary to improve the existing methods and means of their diagnostics. The improvement of the method of speed characteristics control by means of control of test signal current, flowing between the contacts of the switch at its connection or disconnection is very promising.

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Kytin Vasyl − Dc. Sc. (Eng.), Professor with the Department of Electric Stations and Systems, tel.: (0432)-598377.

Rybanenko Olexandre − Cand. Sc. (Eng.), Assistant Professor with the Department of Electric Stations and Systems, tel.: (0432)-598377 e-mail:. Rubanenko@bk.ru.

Vinnytsia National Technical University.

Mysenko Sergix − Engineer, South-West Electric Energy System, service of substations, engineer of substations service, tel.: (0432) – 634951, e-mail: sergey_mysenko@ukr.net.