RESEARCH ON INFLUENCE OF HIGH VOLTAGE CIRCUIT BREAKERS' CHARACTERISTICS ON SWITCHING OVERVOLTAGES AND OVERCURRENTS

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The work presents the results of research of high voltage circuit breakers characteristics' influence on switching overvoltages and overcurrents conditioned by inductive and capacitive load's switchings. The recommendations for the circuit breakers choice from the point of view of permissible levels of voltages and induced e.m.f. in secondary circuits are given.

As is known, the characteristics of circuit breakers mainly have an influence on the process of commutation. In particular, chopping currents of circuit breakers define the peak level of overvoltages during switching off of low inductive currents, law of restoration of di-electric strength affect disconnections of all types of loads and functions of distribution of angle of switching determine the statistical characteristics of current and voltages during switching [1,2]. In addition, according to the reference literature the issues of influence of circuit breakers characteristics (in particular chopping currents and recovering di-electric strengths) to commutation processes, specifically to the processes of switching off of unloaded autotransformers, switching on and switching off of capacitor banks were not completely addressed. The importance of the problem is enforced by the fact that presently "old" (oil and air) circuit breakers get displaced by auto compression and vacuum circuit breakers of the new generation.

The report highlights the results and analysis of numerical researches of influence of circuit breakers characteristics to commutation processes conducted in the Azerbaijan Republic. The information with reference to the applied calculations methodology is given in the Appendix to the paper.

Level of switching overvoltages

It is known that level of switching overvoltages is determined by the characteristics of circuit breakers [1], first of all depending on chopping currents and di-electric strengths. Summarizing (a few) research works carried out in the area of impact of strength characteristics of circuit breakers to the levels of overvoltages, a number of common rules to be identified as follows:

low probability of re-ignitions of switching in disconnection of circuit breaker as the speed of recovery of its di-electric strength grows: according to various sources the abovementioned probability for air circuit breakers is estimated circa 10% and for the oil one – up to 100%. The

results of our research would estimate probability of re-ignitions of circuit breakers is circa (13÷47)% for vacuum and auto compression circuit breakers [3] (whereby the lower probabilities correspond to higher speeds of recovery) and about (70÷75)% for oil ones [4];

- in a certain increase of peak level of commutation overvoltages as the recovery speed of dielectric strength grows: it is known that oil circuit breakers disconnect unloaded transformers "softer", i.e. with less overvoltages than the air ones [1]. The results of our research were similar: the largest estimate ratios were found during switching off of power installations by vacuum circuit breakers and more "soft" auto compression circuit breakers were producing less switching surge [5, 6];

- maximum estimate ratios during switching off of capacitor banks would not exceed level 3 and the same ratios during disconnections of unloaded autotransformers 110÷220 kV do no exceed more than 2,8 [4]. Generally speaking those levels of switching surge are within the levels of acceptable impact on insulation of power installations with standard voltage up to 220 kV inclusive. However, to enable commutation of capacitor banks the probability of the transition of waves of switching surges from the step of the capacitor bank connection to the step of higher voltages [7] with less reserves of isolation levels should be accounted. This possibility is confirmed physically as follows:

a) by relatively low (from the point of view of attenuation) natural (self) frequencies of capacitor banks with the values of around hundreds of Herz [8];

b) by the fact that planned disconnection of capacitor banks mainly takes place in case of increased switching surge in the buses of switch gears, i.e. at relatively high established voltages.

It is obvious that under those conditions the most preferred of all the potential circuit breakers will be those, which would provide the softest switching off of capacitor banks. For example, auto compression circuit breakers are more preferable in comparison with the vacuum ones and among two or more auto compression circuit breakers the most preferred will be the circuit breakers with the minimum speed of recovery of the electric strength dU_{es}/dt, i.e. with the minimum "stiffness". However, if for the given specific scheme the level of switching surges is higher than the level of permissible impacts to insulation it is possible to apply more powerful circuit breakers of higher "stiffness".

It should be noted that strength (dielectric) properties of circuit breakers determine the switching processes and levels of overvoltages. Our researches [6] proved that their impact

to the process in a number of cases can prevail over the influence of chopping currents. The formula for the maximum overvoltage U_{max} when low inductive current is disconnected:

$$U_{max} = i_{ch} (L_\mu C_i^{-1})^{1/2},$$

(where L_μ is induction of idling, C_i is input capacitance of auto transformer; i_{ch} is chopping current with no account of the impact of the recovering di-electric strength of circuit breakers to the level of overvoltages. In our calculations the circuit breakers with lower chopping currents (5A) were producing higher surges compared with the circuit breakers with higher chopping currents (10A) [6]. The reason is that speed of recovery of voltage in circuit breakers's contacts dU/dt are proportional (as is given in correlations shown in [1]).

$$\frac{dU}{dt} \sim (\beta^2 U_o{}^2 + C_i^{-2} i_{ch}{}^2)^{1/2} ,$$

where β is cyclic own frequency; U_0 is voltage at the moment of the current chopping.

According to the given formula it is clear that the more higher the steepness of recovering voltage , the higher the current of chopping i_i. Therefore, in higher chopping currents the repeated breakdowns would be expected during shorter time intervals and correspondingly during lower values of voltage between the contacts of the circuit breakers.

Calculated distribution of probabilities of surge ratios on switching off disconnection of unloaded autotransformer 200 kV are given in Fig.1 These curves were got in the process of series of numerical experiments on models given in [9, 10]. Taking into account that vacuum circuit breakers have lower chopping currents compared with auto compression ones (values 5 A and 10A introduced in the calculations accordingly) and higher speeds of restoration of dielectric strength, the conclusion is that the maximum ratios in case of equal probabilities are conditioned with the law of recovery of dielectric strength. This means that more preferable would be to use more "soft" circuit breakers for auto transformers, transformers and reactors even though with higher value of the chopping current.

Fig. 2. Calculated probabilities of surge ratios on switching off of capacitor banks 110 kV by vacuum circuit breaker

Calculated distribution of probabilities of surge ratios on switchings off of condense battery by the vacuum circuit breakers as shown above in Fig. 2 .

Switching overcurrents and level of induced voltages in secondary circuits

Switching overcurrents of electrical installation have a great practical interest as they are the main reasons of hazardous (short term) impacts to secondary communications and circuits [12].

As currents and voltages of switching regimes affect from one side to electromagnetic compatibility [11] and from the other side they depend on type and characteristics of commutating circuit breakers [4], [5] then the level of switching voltages in secondary circuits may alter depending on choice of circuit breakers. One of the most dangerous commutations with so-called impact to electromagnetic compatibility is switchings (including repeated voltage breakdowns on switching off) of the powerful capacitor bank by auto compression and vacuum circuit breakers (see Fig.3)
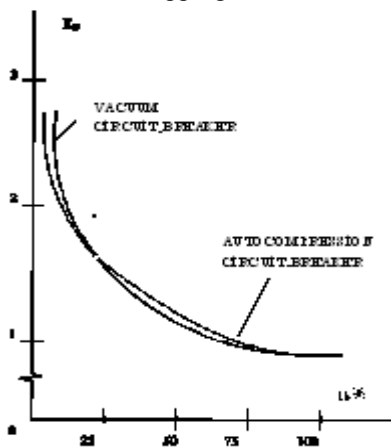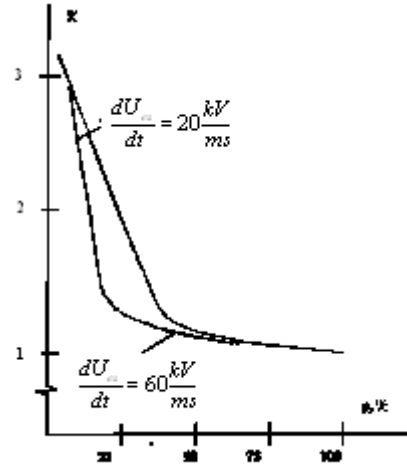

Fig. 1 Calculated probabilities of surge ratios on switchings off of unloaded autotransformer 220 kV by auto compression and vacuum circuit breakers.
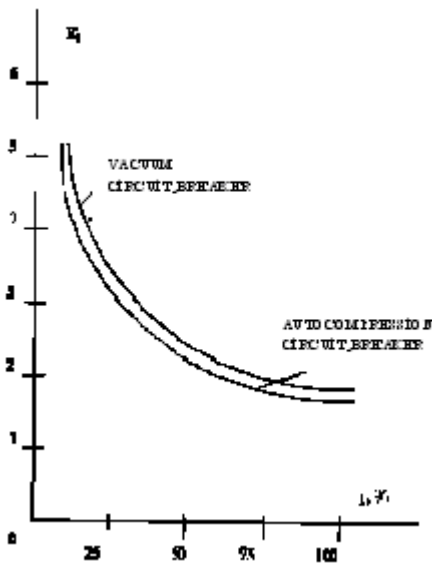
Fig.3 Calculated probabilities of overcurrents ratios on switching on of capacitor banks 110kV by auto compression and vacuum circuit breakers

As is shown in Fig 3, the influence of characteristics of circuit breakers to currents ratios is quite drastic and particularly in the area of low probabilities: as such in the area of probabilities ≤15% the difference between the ratios may reach even 15%. As it was shown in [5], higher ratios of overcurrents of switching take place for high-speed circuit breakers. Thus, in case of proximity of design switching voltage in the secondary circuits to maximum permissible level the most optimal choice of the circuit breakers could in fact provide electromagnetic compatibility of the capacitor banks with the secondary circuits. It goes without saying that in this case it would be necessary to take into account coordination of overvoltages between the levels of permissible impacts to insulation as well (see above). However, it should be noted that more" soft" circuit breakers which produce less overvoltages during switching off and lower overcurrents during electrical installations switching on have higher probability of breakdowns of the between contacts intervals during disconnection compared to "stiff" circuit breakers and that could lead to premature exhaust of resources of secondary circuits elements.

Let's consider one more specific feature of our research. The appliance of so called synchronized or synchronous circuit breakers. Initially those breakers were supposed to be used for long-distance extra-high voltage power transmission lines [12,13]; limitation of overvoltages during connections, including automatic repeated connection is quite important for such lines due to low levels of permissible influences to insulation and from the other side – due to increased steady-state voltages. Synchronous connection was applied to powerful capacitor banks [14]. It is obvious that use of synchronous circuit breakers located in

sensitive electromagnetic environments [15] can require additional measures to provide limitations of induced voltages [15] as the highest making currents are observed in making angles close to zero [5]. It should be noted, however that presently only around a thousand of synchronous high voltage circuit breakers are in operation throughout the world.

Conclusions

The research results provide the evidence of significant dependence of switching voltages and currents on characteristics of circuit breakers. Therefore when choosing circuit breakers as additional condition, the following is to be proposed:

- coordination of level of switching overvoltages with the level of permissible impact to insulation, also when choosing circuit breakers with low or medium-voltage winding, the probability of transformation of overvoltage to windings of higher voltage with lower relative levels of permissible impacts should be noted;
- co-ordination of level of induced voltages in secondary circuits with permissible values of longitudinal induced e.m.f. to improve electromagnetic compatibility.

APPENDIX

On using numerical models

I. Capacitor banks' switchings

a) Circuit (only one phase was shown)
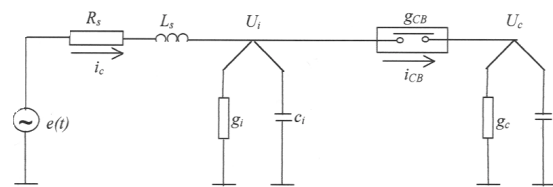
b) Equations

$$\frac{dU_s}{dt} = L_s^{-1}[e(t) - R_s \times i_s - U_L];$$

$$\frac{dU_L}{dt} = C_L^{-1}[i_s - g_L \times U_L - g_{CB} \times (U_L - U_C)];$$

$$\frac{dU_c}{dt} = C^{-1}[g_{CB} \times (U_L - U_C) - g_c \times U_c].$$

c) Conditions of current chopping

$$g_{CB} \times |U_L - U_C| \le i_{ch}$$
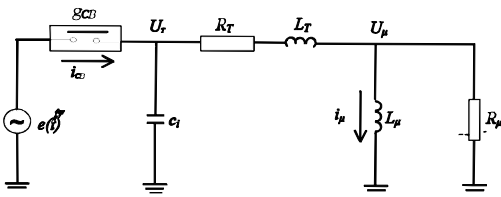
and arc re-ignition

$$|U_L - U_C| \ge U_r(t).$$

d) Nomenclature

R_s, L_s parameters of sourse

g_L, C_L parameters of load

g_c, C parameter of capacitor bank

g_{CB} conductivity of circuit breaker, depending on it's position

$e(t)$ matrix of e.m.f.

i_s, i_{CB} matrixes of currents

i_{ch} chopping current, depending on circuit breaker's type

$U_r(t)$ matrixes of restoring electrical durability of circuit breaker, depenging on it's type.

II. Unloaded autotransformers switching offs.

a) Circuit (only one phase was shown)

b) Equations

$$\frac{dU_T}{dt} = g_{CB}\, C_i^{-1}\, [\, e(t) - g_{CB}^{-1} \times i_T - U_T\,];$$

$$\frac{di_T}{dt} = L_T^{-1}\, (U_T - R_T \times i_T - U_\mu);$$

$$\frac{dU_\mu}{dt} = R_\mu \times \frac{di_T}{dt} - L\mu\text{-}1R\mu \times U\mu.$$

c) Conditions of current chopping

$$|\, i_T + C_i\, \frac{dU_T}{dt}\,| \le i_{ch}$$

and arc re-ignition

$$|\, e(t) - U_T| \ge U_r\,(t)$$

d) Nomenclature

C_i input capacitance of autotransformer

R_T, L_T longitudinal parameters of autotransformer

L_μ, R_μ cross parameters of autotransformer

i_T, i_μ matrixes of currents

U_T, U_μ matrixes of voltages

g_{CB}, $e(t)$, i_{CB} see upon

Described numeriacal models were realised by means of methods of Merson and Fehlberg [16].

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