IMPROVED MODEL OF CIRCUIT-BREAKER'S DIELECTRIC STRENGTH RESTORATION

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Abstract. The paper presents a new way of circuit-breaker's dielectric strength restoration modeling. It is shown that taking into account inconstancy of dielectric strength characteristics of vacuum gaps may improve adequacy at simulation switching processes.

Key words: circuit-breaker's dielectric strength restoration, inter-contact voltage, switching over-voltages

I. INTRODUCTION

Modeling of high-voltage circuit-breaker's dielectric strength restoration is one of the most important problems at computer simulation of transients in power systems. Necessity of taking into account circuit-breakers' characteristics is conditioned by their notable influence on transitional processes, over-voltages and over-currents (e.g. see [1-4]). As it is known the main characteristics of circuit-breakers determined their influence on switching process are dielectric strength restoration, chopping current and full operation time [5].

It was proposed earlier to use a co-sinusoidal law of circuit-breaker's dielectric strength restoration. This law is formalized as following:

$$V_{str}(t) = 2^{-1}V_m\{1 - \cos[\pi(t - t_{off})/T_{full}]\}, \qquad (1)$$

where $V_{str}(t)$ is the acceptable law of circuit-breaker's dielectric strength restoration;

V_m is the maximum value of dielectric strength;

t is time;

T_{full} is the full switch-off time of circuit-breaker;

t_{off} is the initial instant of contact separation [1].

This law: 1) takes into account inertia of contact;

2) is matched good with the movement law of contact;

3) has acceptable coincidence with the real law presented in [6] for auto-compression (elegas) circuit-breakers.

It was shown that the co-sinusoidal law may be used both for auto-compression and vacuum circuit-breakers. This law gives the most successful approximation for real $V_{str}(t)$ curves of auto-compression circuit-breakers. For vacuum circuit-breakers the most of authors use linear restoration law [2, 3].

Concerning to influence of restoration law (linear or co-sinusoidal) we have earlier stated the following:

- using the linear law of circuit-breaker's dielectric strength restoration leads to overestimation of over-voltages calculated ratios both for auto-compression and vacuum circuit-breakers;
- using the linear law of circuit-breaker's dielectric strength restoration leads to underestimation of arc repeated re-ignitions' probability both for auto-compression and vacuum circuit-breakers;
- circuit-breakers presented with linear restoration law have greater "stiffness" from the point of view switching-off processes in comparison with ones presented with co-sinusoidal law [1].

These results are in accordance with general representations of switching over-voltages' theory and also with the main strength characteristics of circuit-breakers.

In general, at computer simulation switching-off processes the law of circuit-breaker's dielectric strength restoration is presented into the following convention of arc repeating re-ignitions appearance:

$$|\Delta V| \geq V_{str}(t), \qquad (2)$$

where ΔV is recovery voltage, i.e. potential difference in inter-contact space of circuit-breaker while arc is quenched [1, 7].

We have before got some results based on presentation of auto-compression circuit-breakers with co-sinusoidal law of dielectric strength restoration and vacuum ones with linear restoration law. These results are known and have been presented e.g. in [4, 8].

Let us now consider how much is quantitative difference of transitional voltages conditioned by the dielectric strength restoration law accepted. According to our researches minded difference between over-voltages ratios may reach or even exceed 10% [1]. The same difference for switching-offs power transmission lines may reach 5% [9].

Note that at obtaining the formula (1) it was proposed that dielectric strength does not depend on inter-contact distance [1]. So this formula was not a priori accepted to vacuum circuit-breakers because that their strength depends on distance (e.g. see [10]). In the same time the linear restoration law given in [2] also is not satisfactory because that it does not take into account inertia of contact.

II. IMPROVED MODEL

We have offered an improved way to modeling the dielectric strength of vacuum circuit-breaker taking into account both inertia of contact and inconstancy of strength of vacuum gaps. Let us consider them.

The formula (1) was got in [1] from the following movement law for circuit-breaker drive:

$$x(t) = 2^{-1}X_m\{1 - \cos[\pi(t - t_{off})/T_{full}]\} \tag{3}$$

at assumption on dielectric strength constancy (X_m is here a maximum distance).

On the other hand the $x(t)$ coordinate in accordance with curves given in [10] determines the instantaneous values of V_{str}, which is presented as a function against x. It may be formalized mathematically as

$$V_{str} = \varphi[x(t)], \tag{4}$$

where φ is an empirical function given in [10].

We have found an approximation of the function for vacuum circuit-breakers given in the (4) form as following

$$V_{str}(t) = 191.43 log\{1 + 5.75 x_m\{1 - \cos[\pi(t - t_{off})/T_{full}]\}\} \tag{5}$$

For comparison in the fig.1 the dielectric strength restoration laws by linear, co-sinusoidal and offered ways are presented graphically (the offered law in conventionally named natural law). The corresponding graphs are consistently denoted as 1, 2 and 3. Note that the offered natural law has been distinguished from the corresponding empirical law by some values changing between -7% and +4% and gives satisfactory approximation for all the switching period.

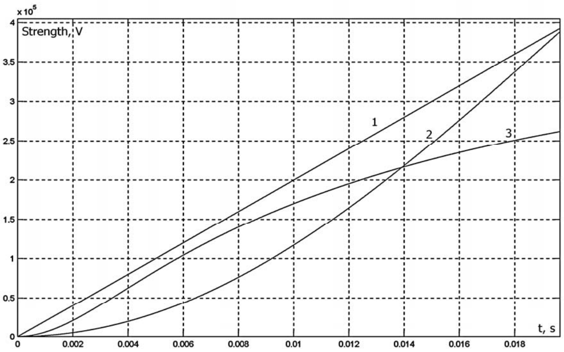

Fig.1. Linear (1), co-sinusoidal (2) and offered (3) laws of vacuum circuit-breaker's dielectric strength restoration

III. DISCUSSION

Let us now consider how the restoration low applied may influence on switching processes.

Below for example the results of computer simulation of transients conditioned by capacitor banks switching-offs are presented (see table). This table lets to compare over-voltage ratios for all the applied ways of circuit-breakers' dielectric strength modeling. The numerical experiments have been carried out were based on corresponding equivalent networks, equations, parameters and conventions given in [4, 6]. Simulation methods and calculation parameters used were presented in [11].

Table. Calculated values of over voltages while switching-off capacitor banks

Accepted restoration law for circuit-breakers dielectric strength \ Jet power of capacitor banks	37.5 MVAr	55 MVAr	75 MVAr	110 MVAr
Linear	2.40	2.53	2.62	2.74
Co-sinusoidal	2.31	2.47	2.58	2.70
Natural	2.58	2.69	2.77	2.84

As it is seemed from the table difference conditioned by the accepted restoration law may has exceeded 10%. We can also see that the greatest over-voltage ratios have taken place at the application of the natural restoration law. As it was noted above this law allows take into account both inertia of circuit-breaker contact and also a dependence of vacuum gaps' dielectric strength on inter-contact distance given in the work [10].

Corresponding calculated curves of transitional voltages are presented in the fig.2, fig.3 and fig.4.

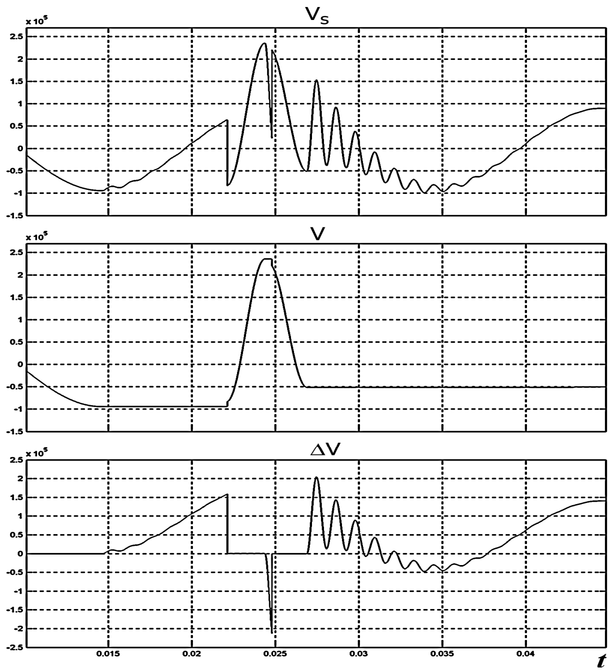

Fig.2. Transitional voltages at use the linear law

Note another quantitative difference brought by the natural restoration law. As we had stated earlier the least probabilities of repeated re-ignitions taken place at switching-off capacitor banks by vacuum circuit-breakers [4, 12]. Using the natural restoration law has allowed us to correct minded estimation. According to our present numerical experiments the minded least probability is less

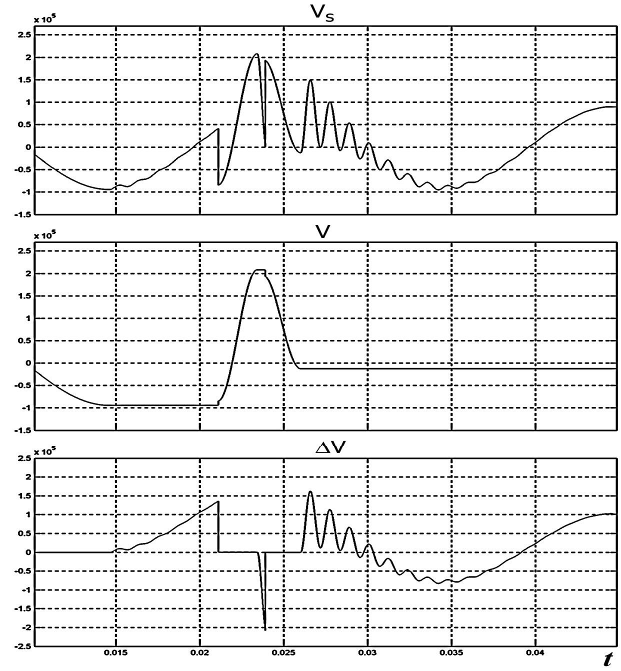

Fig.3. Transitional voltages at use the co-sinusoidal law

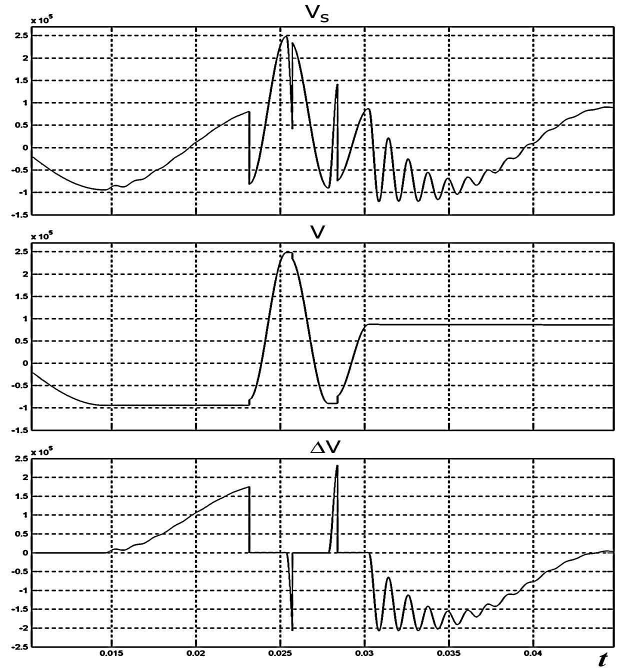

Fig.4. transitional voltages at use the offered law

in comparison with cases of use the other laws. For instance, for probability has changed its calculated value from 13% to 10%.
Such a decreasing takes place for capacitor banks of all the considered jet power
If compare fig.2, 3 and 4 we can notice that for the last case (see fig.4) it takes place 3 repeating re-ignitions, whereas for the cases of use the linear and co-sinusoidal laws we had just 2 repeating re-ignitions.

IV. CONCLUSION

The new law of vacuum circuit-breakers' dielectric strength restoration is considered. The offered law takes into account both inertia of circuit-breaker's contact and inconstancy of strength along vacuum inter-contact gap. It has been stated that at use of the new model take place greater over-voltages ratios and less probabilities of repeated re-ignitions while switching-off capacitor banks (in comparison with use other known restoration laws). The over-voltages ratios for the cases of capacitor banks of 37.5-110 MVAr switching-offs has been calculated.

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