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ENERGETIC STRESSES OF SURGE ARRESTERS WHEN SUBJECTED TO SWITCHING OVERVOLTAGES IN 10 kV, 20 kV AND 35 kV NETWORKS

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ABSTRACT

The paper deals with the energetic stresses of metal-oxide surge arresters without spark gap when subjected to switching overvoltages in 10 kV, 20 kV and 35 kV networks. Consideration is carried out for afore cited networks earthed through a resistor and a reactance and neutral isolated networks. Switching overvoltages, and stresses due to them on the metal-oxide surge arresters without spark-gap, were calculated at switching-in and switching-out of: overhead lines, transformers, capacitor banks as well as at establishing and interruption of earth-fault. It is concluded that power stresses of surge arresters are low. Even for the highest switching overvoltages they rarely surpass a few kJ. Their energy absorption capability from the viewpoint switching overvoltages, should not be over 6.5 kJ/kV_{Ur}.

1. INTRODUCTION

Metal-oxide surge arresters without spark-gap (MOA) are very effective means for protecting the equipment in high-voltage networks from lightning and switching overvoltages. In 35 kV, 20 kV and 10 kV networks, they are used solely for power transformers protection from overvoltages. At their selection, besides rated voltage, special care should be paid to energy absorption capability. It is used to define the quantity of energy which can be absorbed by non linear resistors without their damaging. The price of the MOA having the same rated voltage grows with the enlargement of its energy absorption capability. The choice of MOA energy absorption value should be based on energetic stresses to which they will be exposed in exploitation. In this paper were considered the energetic stresses of the MOA to which they are expected to be exposed in the 10 kV, 20 kV and 35 kV networks during exploitation at the appearance of switching overvoltages.

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2. BASIS FOR THE CALCULATION OF SWITCHING OVERVOLTAGES AND ENERGETIC STRESSES OF MOA

The calculations of switching overvoltages and energetic stresses of MOA due to them were carried out by using ATP EMTP program.

The foundations which were used in the calculations of switching overvoltages and energetic stresses of MOA due to them are the following P.Vukelja (1):

- Overhead lines are presented by distributed, frequency dependent, parameters, by means of the wave impedances and the propagation velocities for positive and zero sequence.
- Power transformers are presented by inductance matrix gained on the basis of their data and windings capacitances between each other and to the ground.
- The network is equalized by means of the voltage generator and corresponding impedances.
- MOA are presented with protective characteristic for switching overvoltages.

For protective characteristics of MOA were used MOA characteristics which already are or will be found in the 35 kV, 20 kV and 10 kV networks of Serbia. These are MOA having the following rated (U_r) and continuos operating (U_c) voltages:

● network earthed through a resistor or a reactance:

- U_r = 39 kV, U_c=32 kV for 35 kV network,
- U_r = 24 kV, U_c=20 kV for 20 kV network,
- U_r = 12 kV, U_c=10 kV for 10 kV network.

● networks with isolated neutral point:

- U_r = 51 kV, U_c = 42 kV for 35 kV network,
- U_r = 34 kV, U_c = 28 kV for 20 kV network,
- U_r = 18 kV, U_c = 15 kV for 10 kV network.

Their protective characteristics for switching overvoltages are given in table 1. Protective characteristics for currents below 1 kA for switching surges are defined on the basis of experimental investigations of non-linear ZnO resistors, carried out in the Institute “Nikola Tesla” Z.Zdravkovic (2).

TABLE 1 - PROTECTIVE CHARACTERISTICS OF MOA FOR SWITCHING OVERVOLTAGES

NETWORK	MOA		RESIDUAL VOLTAGE (kV) - FUNCTION OF CURRENT					
	U_r (kV)	U_c (kV)	1 mA	5 mA	250 mA	0.25 mA	1 kA	3 kA
Network earthed through resistor or reactance	39	32	45	55	62	72	76	80
	24	20	28	34	39	46	50	53
	12	10	14	17	19	22	25	26
Network with isolated neutral point	51	42	59	72	86	98	105	108
	34	28	39	48	56	65	70	73
	18	15	21	25	28	33	37	39

3. CALCULATION OF ENERGETIC STRESSES OF MOA SUBJECTED TO SWITCHING OVERVOLTAGES

Energetic stresses of a MOA subjected to switching overvoltages were considered in the following cases:

- switching-in and switching-out of overhead lines,
- switching-in and switching-out of transformers at no-load,
- switching-in and switching-out of overhead lines terminated with power transformers at no-load,
- establishing and interruption of an earth-fault, energization and de-energization of capacitor banks.

All these considerations were carried out in the 35 kV, 20 kV and 10 kV networks earthed through a resistor or reactance and in the networks with isolated neutral point.

3.1. Switching-in and switching-out of overhead lines

3.1.1. Switching-in of overhead lines. The calculation of power stresses of MOA were carried out in the following cases:

- Switching-in unloaded overhead lines,
- three-phase automatic reclosing (3AR) of the circuit-breakers of overhead lines.

This is done for 35 kV, 20 kV and 10 kV overhead lines. The lengths of the lines were varied from a few hundred meters up to 4o km for 35 lines, up to 20 km for 20 kV lines and up to 10 km for 10 kV lines.

For every line of chosen length the calculations were carried out for a thousand of its switchings-in at unloaded condition and a thousand of 3AR. By random numbers method, from the assumed normal distribution of the closing time of circuit-breaker poles, the closing times have been chosen. As standard discrepancy of the closing time of circuit-breaker poles σ = 1,7 ms was adopted.

Calculations at 3AR of overhead lines, after earth-fault clearance, have been performed when the residual voltage on phases on which an earth fault did not occur is approximately equal to the peak value of the phase-to-phase voltage before earth-fault occurrence.

At switching-in of unloaded lines and at 3AR, the energetic stresses were calculated of MOA in the substation from which the circuit-breakers of the lines were switched-in, since in the 35 kV, 20 kV and 10 kV networks MOA are not installed at the ends of the lines. The following is concluded:

- Switchings-in of unloaded 35 kV, 20 kV and 10 kV lines lead to insignificant stresses of MOA, since switching overvoltages appearing in this case on the insulations in substation, and on the MOA terminals as well, rarely surpass 1.5 p.u..
- 3AR of 35 kV, 20 kV and 10 kV overhead lines, although they give rise to higher overvoltages than normal switchings-in of the same lines, the absorbed energy by MOA do not surpass a few hundred J, even for the longest lines in the networks earthed through a resistor or a reactance. In the networks with isolated neutral point, their energetic stresses are insignificant.

Energetic stresses of MOA were also calculated in the cases when they are positioned at the ends of overhead lines. Calculations were performed at switching-in of the lines and at 3AR.

Energetic stresses of the MOA at the beginnings of lines at their switching-in are insignificant; at the ends of lines they are a bit higher, but the absorbed energies rarely reach a few tens of J. 3AR give rise to somewhat higher energetic stresses of MOA. In the networks earthed through a resistor or a reactance at 3AR of lines, absorbed energies by MOA at the beginnings of lines reach several hundred J, and at the ends of lines up to a few kJ. However, in the networks with isolated neutral point their energetic stresses at the beginnings and at the ends of lines at switching-in and at 3AR are insignificant.

3.1.2. Switchings-out of overhead lines. Calculations of energetic stresses of MOA were carried out at switching-out of overhead lines when in the circuit breaker, by which they are switched-out, there are no arc re-establishments and when they occur.

At switching-out of unloaded 35 kV, 20 kV and 10 kV lines, when there are no arc re-establishments in the circuit-breaker, there are no overvoltages and therefore no energetic stresses of MOA in substation.

Switchings-out of the 35 kV, 20 kV and 10 kV lines, when in the circuit-breaker arc re-establishments occur, they can lead to relatively high overvoltages, but even in this case significant energetic stresses of MOA do not take place. Absorbed energies of MOA-s in substation even at multiple arc re-establishments rarely have surpassed 1.5 kJ.

Calculations, performed for the cases of electric arc re-establishment in the circuit-breaker, when MOA are present at the ends of 35 kV, 20 kV and 10 kV lines, show that the energy which they absorb do not surpass 2.5 kJ.

3.2. Switchings-in and switchings-out of power transformers at no-load

Calculations of energetic stresses of MOA were performed at switching-in 35kV/10 kV, 35 kV/0.4 kV, 20 kV/0.4 kV and 10 kV/0.4 kV transformers at no-load , by circuit-breakers on higher voltage side. The statistical approach here is not applied but the times of switching-in the poles of the circuit-breaker which give rise to the highest overvoltages on transformer terminals have been chosen, and they did not surpass 1.9 p.u. Energetic stresses of MOA on the transformer higher voltage and lower voltage side are insignificant.

Calculations, carried out at switching-out of afore cited transformers at no-load by means of circuit-breakers on the higher voltage side, show that in the cases of current passing through natural zero there are no overvoltages and therefore no energetic stresses of MOA. At cutting the current before passing through natural zero the absorbed energy by MOA rarely surpass a few hundred J.

3.3. Switchings-in and switchings-out of lines loaded with transformer at no-load

Calculations of energetic stresses of MOA were carried out in the following cases:

- switching-in of lines loaded with transformer at no-load,
- 3AR of lines loaded with transformer at no-load.

Calculations of energetic stresses of MOA were carried out at switching-in and at 3AR of 35 kV lines with 35kV/10kV and 35kV/0.4 kV, transformers, 20 kV lines with 20kV/0.4 kV transformer and 10 kV lines with 10 kV/0.4kV transformer. Statistical approach is applied (like in part 3.1.1.). A thousand of switchings-in and 3 AR as well, is carried out for investigated configurations.

Absorbed energies by MOA in substation from which the 35 kV, 20 kV and 10 kV lines were switched-in are insignificant; absorbed energies by MOA at the ends of lines that is, on the transformer terminals even for the longest lines do not surpass a few hundred J.

Absorbed energies by MOA at the beginning of 35 kV, 20 kV and 10 kV lines at 3AR do not surpass a few hundred J, and at transformer terminals for longest lines do not surpass a few kJ.

As an example, in fig. 1 is presented the histogram of the absorbed energy distribution of the MOA installed at the end of 35 kV line, 30 km long, that is, at 35 kV terminals of the 35 kV/10 kV transformer at a thousand switchings-in of the same line loaded with 35 kV/10 kV transformer at no-load; 35 kV network is grounded through a resistor. In fig. 2 the same is presented only for a thousand 3AR of the same line.

The calculations were carried out for switching-out of afore mentioned lines with transformer at no-load at their end, show that the stresses of MOA at the beginning and at the end of lines are insignificant.

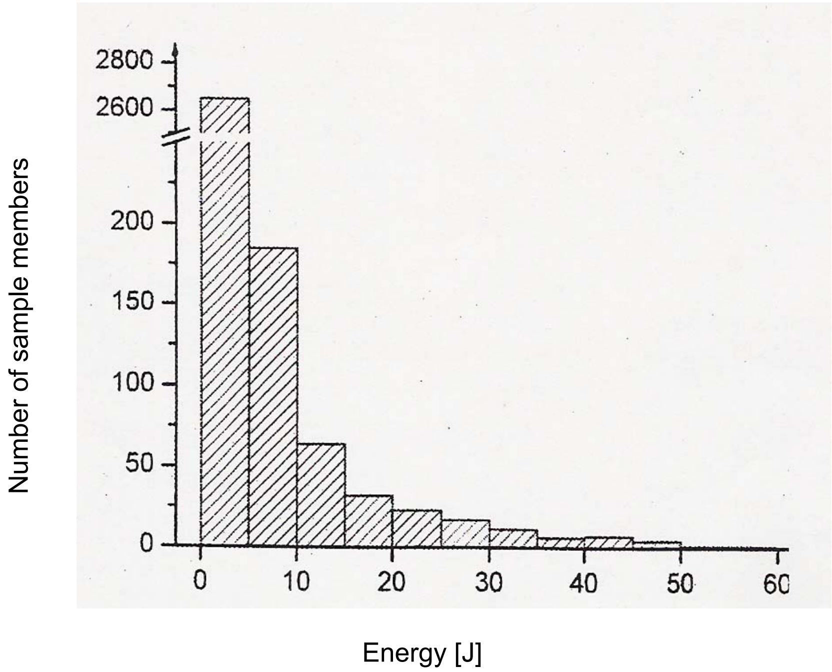

Fig. 1 Histogram of absorbed energy distribution of MOA at the end of 35 kV, 30 km long line, that is, at 35kV/10 kV transformer terminals, at thousand switchings-in of the same line loaded with 35kV/10kV transformer at no-load, in the 35 kV network grounded trough a resistor.

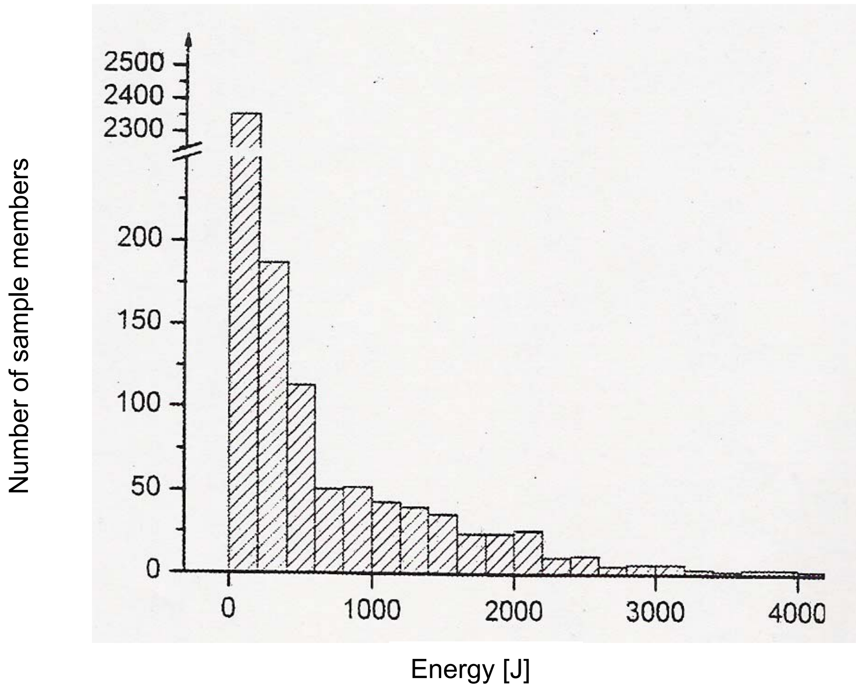

Fig. 2 Histogram of the absorbed energy distribution of MOA at the end of 35 kV, 30 km long line, that is, at the 35 kV/10 kV transformer terminals, at a thousand 3 AR of the same line loaded with 35 kV/10 kV transformer at no-load, in the 35 kV network grounded through a resistor.

3.4. Calculations of energetic stresses of MOA at establishing and interruption of earth -fault

Energetic stresses of MOA were considered at establishing and interruption of an earth-fault on 35 kV, 20 kV and 10 kV lines. It is established that in this case high overvoltages do not appear on the lines (up to 2.5 p.u.) and absorbed energies by MOA are small; they rarely surpass a few hundred J. Temporary overvoltages remaining on the line till ground fault is cleared cannot damage MOA energetically since they are just chosen to withstand overvoltages in the course of earth-fault duration P Vukelja (3). Higher energetic stresses of MOA can be expected at the appearance of an intermittent earth-fault in the networks with isolated neutral point.

3.5. Switchings-in and switchings-out of capacitor banks

Calculations of energetic stresses of MOA were carried out at switching-in and switching-out of 35 kV, 20 kV and 10 kV capacitor banks in 110kV/35kV substation, 110kV/20kV substation and 35kV/10kV substation. 35 kV, 20 kV and 10 kV networks are grounded through a resistor.

At switching-in 35 kV, 20 kV and 10 kV capacitor banks overvoltages higher than 2 p.u. do not appear. Energetic stresses of MOA in this case are insignificant.

Energetic stresses of MOA at switching-out of 35 kV, 20 kV and 10 kV capacitor banks were discussed in the cases when there are no arc re-establishments between circuit-breaker contacts through which they are switched-out, and when they appear.

When switchings-out of circuit-breakers develop without arc re-establishments between circuit-breaker contacts, there are no overvoltages and therefore no energetic stresses of MOA.

In the case of multiple arc re-establishments between circuit-breaker contacts, significant overvoltages may appear on the capacitor bank side, and somewhat lower on the transformer side. Absorbed energies by MOA, which are at transformer terminals, rarely surpass a few kJ: With mounting a MOA at the capacitor bank terminals overvoltages are limited. Absorbed energies of these MOA can reach even several tens of kJ.

4. CONCLUSIONS

On the basis of investigations on energetic stresses of MOA subjected to switching overvoltages in 35 kV, 20 kV and 10 kV networks the following can be concluded:

- Energies absorbed by MOA mounted for transformer protection, when exposed to overvoltages due to switchings-in and switchings-out of: lines, transformers, and at the appearance of an earth fault, are small. They do not surpass a few kJ, and therefore absorption capability of MOA from the viewpoint overvoltages, can be even below 0.5 kJ/kV_{Ur}.
- Where MOA are used to protect the insulation of capacitor banks from switching overvoltages (they are necessary only in the case where at their de-energization high overvotlages appear due the frequent re-establishments of electric arc in the circuit-breaker), it is necessary to have their absorption capability in the order of 2-3 kJ/kV_{Ur}.

In the 35 kV, 20 kV and 10 kV networks with isolated neutral point it is necessary to prevent the possibility of ferroresonant oscillations appearance, since they can provoke energetic stresses of MOA considerably above permitted, even for those having absorption capability of a few kJ/kV_{Ur}.

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