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MEĐUNARODNO REGIONALNO SAVETOVANJE O ELEKTRODISTRIBUTIVNIM MREŽAMA
REGIONAL CONFERENCE AND EXHIBITION ON ELECTRICITY DISTRIBUTION
Crna Gora, Herceg Novi, 5 - 8. oktobar 2004. / ***Montenegro, Herceg Novi, October 5 - 8, 2004***
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SELECTION OF THE SURGE ARRESTER ENERGY ABSORPTION CAPABILITY RELATING TO LIGHTNING OVERVOLTAGES

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ABSTRACT

The paper presents the research of the risk of surge arrester failure due to the exceeding energy absorption capability when stressed by lightning overvoltages. The influence of the number of overhead lines connected to substation on the surge arrester failure rate is analyzed. Also, the influence of earth wire and the influence of tower footing impedance and energy absorption capability on surge arrester failure rate are investigated.

1. INTRODUCTION

The main difference between the high voltage and the medium voltage metal oxide surge arresters behavior is in the absorbed energy during the discharge period, when stressed by various kinds of overvoltages. High voltage metal oxide surge arresters are stressed mostly by the switching overvoltages causing a great portion of electrical charge to flaw through the arrester during the whole period of the overvoltage existence. On the other hand, the medium voltage surge arresters are stressed mostly by the direct lightning strokes close to the protected object. For the high voltage metal oxide surge arresters there are standard methods for the energy absorption capability selection based on the line discharge energy estimation [1]. The medium voltage surge arrester absorbed energy caused by the lightning discharge can be estimated by analytical methods [2]. The arrester energy absorption capability is tested by the standard short duration current wave simulating a lightning discharge or by the rectangular long duration current wave simulating a switching surge. The first results of the present study are presented in [3] an in current paper some additional results are presented.

In the paper the surge arrester stresses caused by the lightning discharges to the medium voltage overhead lines connected to substation are considered. The surge arrester absorbed energy is computed by the specialized computer program for the direct and the indirect lightning overvoltage computation and line and substation insulation failure rate estimation. The program has the user friendly graphical interface in the Windows environment enabling a simple equivalent circuit creation. The influence of the number of overhead lines connected to the substation on surge arrester failure rate will be analyzed in the paper. In addition, the influence of earth wire on the surge arrester failure rate and the influence of tower footing impedance and surge arrester energy absorption capability will be investigated.

2. ESTIMATION OF THE MEAN TIME BETWEEN THE FAILURES OF THE SURGE ARRESTER

The computation method for the mean time between failures (MTBF) of the surge arrester caused by the lightning discharge is based on the modified lightning limiting parameter method, which is primarily applied for the risk of the

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insulation failure estimation. The surge arrester absorbed energy is computed during the transient process simulation by the following relation:

$$W = \int_{t_o}^{t} u_A(t) i_A(t) dt \tag{1}$$

where:

W - is the energy released in the surge arrester during the discharge process, expressed in Joules,
$u_A(t)$ – the instantaneous voltage across the arrester expressed in Volts,
$i_A(t)$ – the instantaneous value of the discharge current through the arrester expressed in Amps,
t_0 – the moment of the first appearance of the lightning overvoltages at the surge arrester terminal,
t – current time instant expressed in seconds.

The transient simulation is performed with the single lightning current wave of certain magnitude I_i. In every computation time step the released energy in the surge arrester W is compared with the surge arrester energy absorption capability A. At the time moment t_A when the released energy W becomes greater than the energy absorption capability A, the simulation is interrupted. The total lightning charge released from the beginning of the discharge process up to the moment t_A is computed. The computation method is based on the calculation of the total lightning charge released in the flash until exceeding the surge arrester energy absorption capability [3]. The total lightning charge released until the surge arrester failure can be computed by the following relation :

$$Q = \int_{t_0}^{t_A} i(t - t_0)\, dt \tag{2}$$

where:

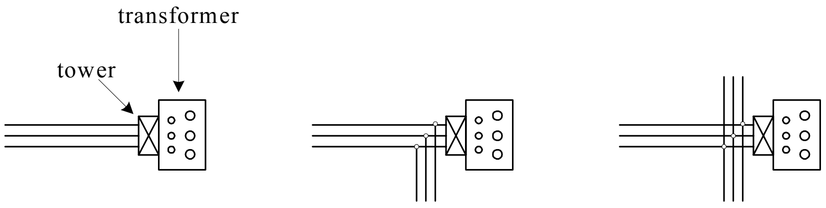
Q – the electrical charge flowing down the lightning channel to the discharge point,
$i(t)$ – the lightning current flowing to the discharge point,
t_0 – the time instant in which the lightning surge arrives to the arrester,
t_A – the time instant in which the surge arrester energy absorption capability is exceeded, according to relation (1)

After computing the electrical charge sufficient to cause exceeding of the surge arrester energy absorbtion capability, the next transient simulation with greater lightning current magnitude is started. In every transient process simulation the pair of lightning parameters (the current magnitude and the charge flowing through the lightning channel to the discharge point sufficient for the surge arrester failure), is determined.

The lightning current wave-form is modeled by the linear rising front and the linear falling tail. The natural negative lightning flash consists from several components with the inter-stroke periods with a continuous current flowing through the lightning channel.To simplify the computation procedure, instead of the multiple flash an equivalent single stroke is applied

3. SENSITIVITY ANALYSIS OF THE NUMBER OF OVERHEAD LINES CONNECTED TO TRANSFORMER SUBSTATION ON THE SURGE ARRESTER FAILURE RATE

The influence of number of lines connected to the pole mounted transformer on the surge arrester energy stress is analysed. Possible dispositions of transformer tower substations with overhead lines at rated voltage of 10 kV are presented in Figure 1.



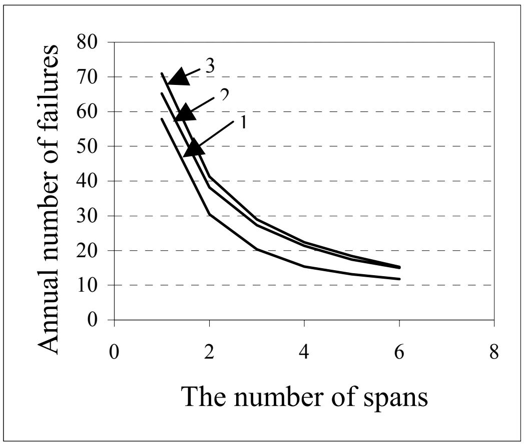
a) arriving line b) arriving and departing line c) T connection

Picture 1: Configurations of tower substantion with various number of overhead lines connected to

Three equivalent networks for the influence analysis of the number of overhead lines connected to transformer substation are formed:

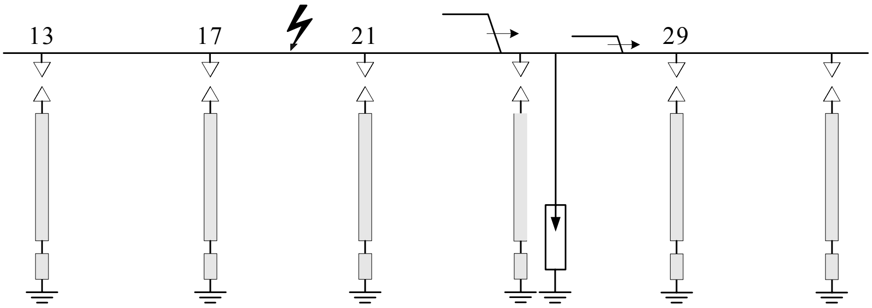
- One line struck by lightning discharge connected to the substation, consisting from 10 spans,
- One line struck by lightning discharge connected to the substation,, consisting from 10 spans and anopther line cosisting from 4 spans also connected,
- One line struck by lightning discharge connected to the substation,, consisting from 10 spans and two other lines cosisting from 4 spans also connected,

In Figure 2 the mean time between surge arrester failures as a function of the number of spans affected by lightning discharges, in case if 1,2 or 3 lines connected to transformer substation, is presented.



Picture 2: The mean time between failures as a function of the number of spans affected by Lightning discharges, in case if 1, 2 or 3 lines connected to transformer

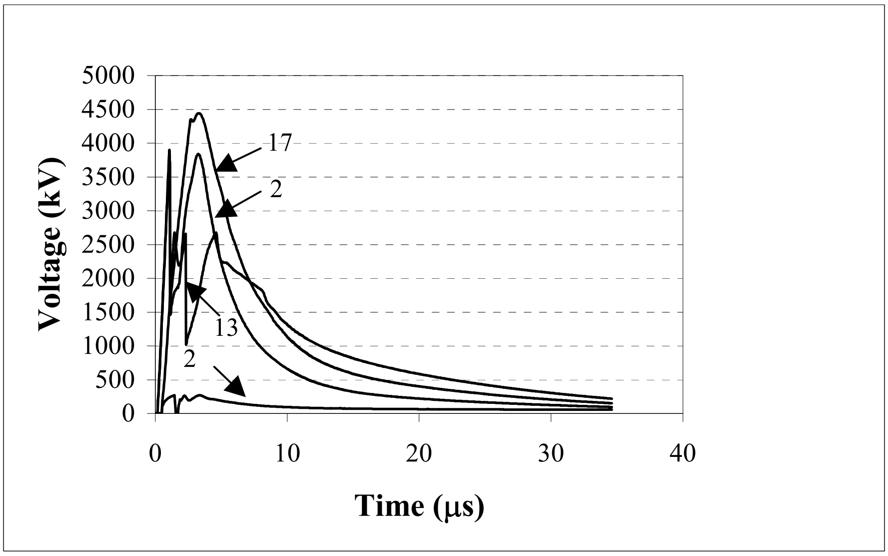
The investigation of voltage wave-shape at transformer terminal when overvoltage wave propagates along the overhead line affected by lightning discharge in the second span is performed. It is found that the voltage is reduced when passed the surge arrester and doesn't cause insulation flashover at other lines connected. Therefore, only a small amount of energy is transmitted along the phase conductors behind the surge arrester. In Figure 3 the analysed network with the points of voltage registration in front of and behind the surge arrester is presented and in Figure 4 these voltages are presented as a function of time.



Picture 3: Analysed network with the points of voltage registration

It can be noticed that the voltages at points 13, 17 and 21 on line affected by overvoltage wave are much higher than the voltage at point 29 behind the surge arrester. Futhermore, at points 13, 17 and 21 the insulation flashover can be noticed, meanwhile, it doesn't occur at point 29 behind the surge arrester.

According to these analysis it can be concluded that the number of the connected overhead lines has small influence on surge arrester stress reduction because the energy released in surge arrester is influenced only by a change of the equivalent surge impedance of the lines connected to transformer substation and the tower footing impedances behind the surge arrester have no influence because the insulation flashover doesn't occur.



Picture 4: Voltages at signed points in front of and behind the surge arrester

4. SENSITIVITY ANALYSIS OF THE GROUND WIRE ON THE SURGE ARRESTER FAILURE RATE

Practically, in the medium voltage networks every lightning discharge hitting the line without ground wire causes insulation flashover. However, if the line has the ground wire, even when the tower footing impedances are small, the insulation flashover also occurs due to small insulation level of towers. This is the main reason why the installation of ground wire is not recommended for the medium voltage lines.

In Fig 5 the analyzed tower with and without earth wire geometries are shown.

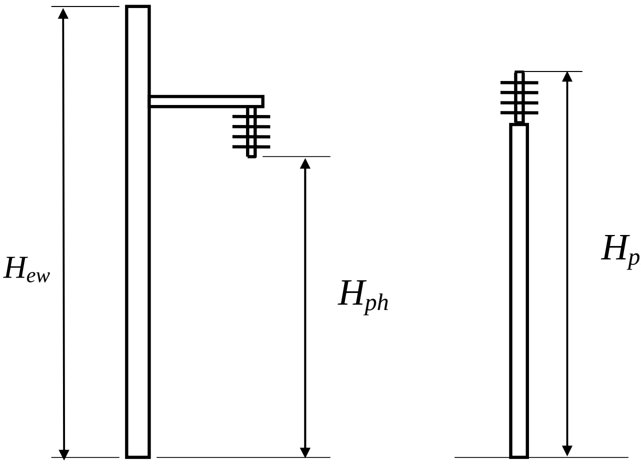


Figure 5: The analyzed towers with and without earth wire geometry

The attractive area of the line with earth wire is calculated relating to the earth wire high H_{ew}=16 m. The attractive area of the line without earth wire is calculated relating to the phase conductor high H_{ph}=10 m.

The sensitivity analysis of the earth wire to the surge arrester energy stress is performed. Figure 6 shows the equivalent network consisting 10 line spans, earth wire where happened lightning strike and transformer modeled by the surge capacitance, protected by the ZnO surge arrester.

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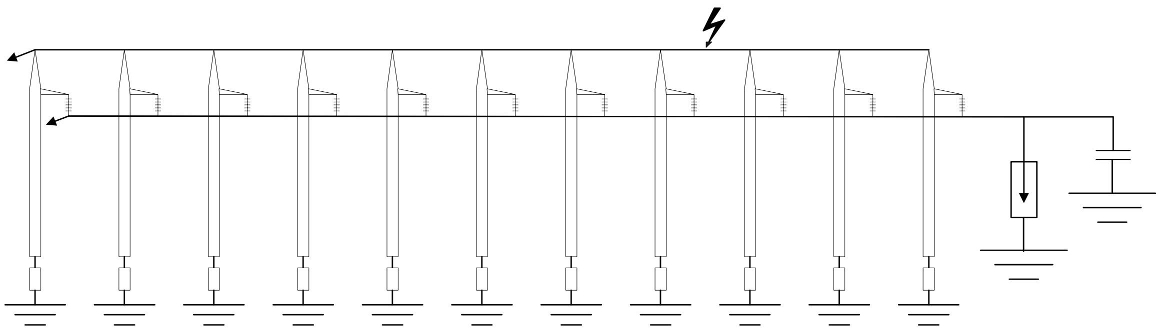

Figure 6: The equivalent network for the sensitivity analysis of the ground wire on surge arrester energy stress

The computation is performed for various lightning discharge point locations along first 6 spans in front of transformer. The strikes to the further spans have no effect to the mean time between failures (MTBF) of the surge arresters. The surge arrester energy absorption capability used in the model is 3,5 kJ/kV of the rated voltage. The calculations are performed for the various values of the tower footing impedance (15, 30, 50 and 100 Ω) and for system voltages of 35 kV and 20 kV. The results are presented in Fig. 7 for 35 kV line left and for 20 kV line right. The tower footing resistance was varied from 15 to 100 Ω. In all calculations instead of impulse tower footing impedance model the constant steady state of the footing resistance is applied, because the impulse period of the tower footing impedance is very short and without any effect to the absorbed energy of the surge arrester.

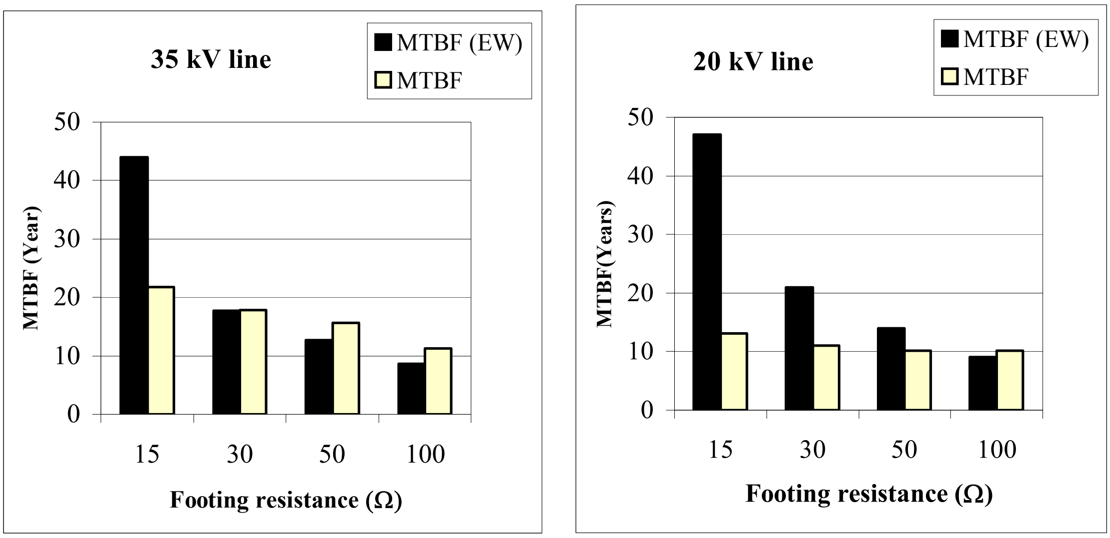

Figure 7: The mean time between surge arrester failures for the line with and without grounding wire for 35 kV system voltage (left) and 20 kV system voltage (right) in dependence of tower footing resistance

It can be concluded that the ground wires have influence on surge arrester stress reduction only in the case of 15 Ω tower footing resistance. For towrr footing resistance of 30 Ω in 35 kV system the MTBF is equal for line with and without erath wire and in the case of the tower footing resistance greater than 30 Ω in 35 kV system the erath wire have the opposite effect increasing the attractive area and decreasing the MTBF. For 20 kV system increasing the tower footing resistance decreases the MTBF for both lines with and without erath wire.For tower footing resistance of 100 Ω for 20 kV system the MTBF is greater in the system without erath wire. However, the number of lightning discharges is greater due to greater line high when it has ground wire. It can be concluded that only in the system where tower footing resistance of first few towers in front of the substation has very small tower footing resistance it is possible to increase MTBF of the surge arrester by introducing the earth wire. Interesting is the fact the in the system without earth wire reduction of the tower footing resistance cannot significantly increase MTBF of the surge arresters.

The sensitivity analysis of tower footing impedance which is varied in a large range to the surge arrester failure rate for three medium voltage levels is performed. The surge arrester energy absorption capability used in the analysis is 5.6 kJ/kV of the rated voltage. In the Figure 8 the influence of tower footing impedance to surge arrester failure rate is presented for three voltage levels.

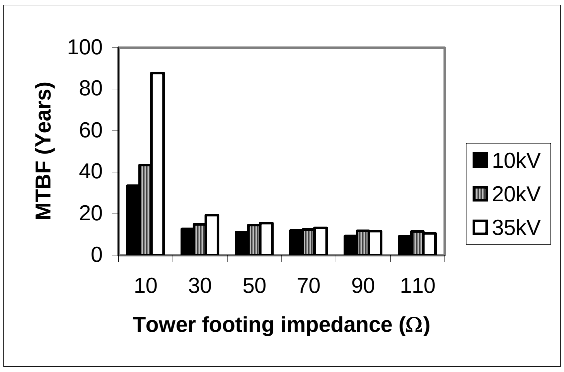

Figure 8: The influence of tower footing impedance on surge arrester failure rate in three nominal voltage systems

It can be concluded that the increase of tower footing impedance above 10 Ω causes great increase of the number of surge arrester failures. Practicaly, the same MTBF are obtained for the tower footing resistance from 30 Ω to 100 Ω. Therefore, it is important for the first 5-6 towers in front of the surge arrester to have tower footing impedance less then 20 Ω.

5. SENSITIVITY ANALYSIS OF THE ENERGY ABSORPTION CAPABILITY TO THE SURGE ARRESTER FAILURE RATE

The systematic computation of the MTBF of surge arresters of various energy absorption capabilities when applied in networks of various tower-footing impedances was performed. In Table 1 the MTBF of the surge arrester of rated voltage 18 kV applied in 10 kV network with insulated neutral point.

Table 1.: Surge arrester MTBF dependence on the energy absorption capability and tower footing resistance in 10 kV network

MTBF								
A (kJ/kV)	10	20	30	40	50	60	70	80
1	15.73	11.20	9.79	7.33	6.90	6.68	6.40	5.92
2	37.19	14.85	11.37	9.98	9.06	8.43	7.94	7.45
3	65.76	22.01	14.45	12.81	11.76	10.98	10.45	9.98
4	128.88	36.34	19.43	15.33	14.26	13.35	13.01	12.91
5	241.02	59.23	28.80	19.70	16.81	15.77	15.30	14.91
6	606.54	108.18	46.70	27.53	21.59	18.64	18.20	17.91

In Table 2, the computation results of the surge arrester of the rated voltage 36 kV applied in the insulated neutral network of the nominal voltage 20 kV are presented.

Table 2.: Surge arrester MTBF dependence on the energy absorption capability and tower footing resistance in 20 kV network

MTBF								
A (kJ/kV)	10	20	30	40	50	60	70	80
1	26.53	16.15	9.98	9.10	8.20	7.80	7.50	6.91
2	84.92	30.59	16.50	12.54	11.53	10.50	10.25	9.90
3	219.90	57.58	28.12	17.20	14.60	14.10	13.10	12.70
4	615.01	115.83	52.30	27.37	19.23	17.00	16.20	16.00
5	1973.15	263.58	103.29	48.94	30.10	22.36	19.30	19.10
6	4386.00	650.00	229.39	96.61	53.33	35.06	22.50	20.10

In Table 3, the computation results of the surge arrester of the rated voltage 54 kV applied in the insulated neutral network of the nominal voltage 35 kV are presented.

Table 3.: Surge arrester MTBF dependence on the energy absorption capability and tower footing resistance in 35 kV network

A (kJ/kV)	10	20	30	40	50	60	70	80
1	35.70	14.37	9.85	8.55	7.80	7.77	6.79	6.78
2	83.00	27.69	16.05	11.98	10.74	10.70	9.41	9.40
3	211.70	52.89	27.40	17.44	13.82	13.70	11.93	11.38
4	581.60	102.45	49.21	27.13	19.21	18.60	14.44	13.79
5	1535.50	216.15	96.63	47.82	30.07	28.75	18.69	16.83
6	4332.40	484.89	210.00	93.88	52.60	49.06	27.10	22.60

In [8] the permissible MTBF of 25 years is adopted for transmission line arresters of 138 kV and 230 kV systems. If this criterion is adopted, than the minimum energy absorption capability of surge arrester in dependence of tower footing impedance of the impinging lines can be determined. In Table 4 the minimum energy absorption capability of ZnO surge arrester for different tower footing resistances and voltage levels is presented, in the case of insulated neutral point systems.

Table 4.The minimum energy absorption capability of ZnO surge arresters for different tower footing resistances and voltage levels in the case of isolated neutral point networks.

MTBF								
U(kV)	R_{uz} (Ω)							
	10	20	30	40	50	60	70	80
10 кV	2	4	4	6	10	10	10	10
20 kV	1	2	3	4	5	6	6	10
35 kV	1	2	3	4	5	5	6	10

From Table 4, according to tower footing resistance of the impinging line to the transformer the corresponding energy absorbtion capability of surge arrester can be selected for corresponding voltage level. In similar way for grounded neutral point system the minimum energy absorbtion capability can be selected. For instance in 10 kV network, for 30 Ω tower footing resistance 4 kJ/kV of rated voltage should be selected.

In the estimation of the minimum energy absorption capability, it is assumed that every direct lightning strike to the phase conductor of the medium voltage overhead line at the metal towers without earth wires cause the flashover between all three phases at the span or at the closest tower. It means that the overvoltage wave is propagating along all three phases toward the surge arresters. The total lightning energy is divided into the equal parts at every of three surge arresters. In single conductor equivalent circuit, the surge arrester is modeled by three times greater energy absorption capability taking into account effect of the energy sharing between three arresters during the discharge.

It must be empahasised that the footing resistance of the tower here transformer is mounted doesn't affect the surge failure of the surge arrester at all.

6. CONCLUSION

From the sensitivity analyses of the medium voltage ZnO surge arrester failure rate due to the lightning overvoltages the following conclusions can be emphasized:

1. The number of the connected overhead lines has small influence to the surge arrester stress reduction because the energy released in surge arrester is influenced only by a change of the equivalent surge impedance of the lines connected to transformer substation and the tower footing impedances behind the surge arrester have no influence because the insulation flashover doesn't occur at these lines.
2. The ground wires have no great influence on surge arrester stress reduction. However, the number of lightning discharges is greater due to greater line high when it has ground wire, and therefore, the number of surge arrester failures is greater. For that reason, the installation of ground wire is not recommended for the medium voltage lines.
3. The increase of tower footing impedance above 10 Ω causes great increase of the number of surge arrester failures.
4. It is possible to compute MTBF of ZnO surge arresters for various tower footing resistances and surge arrester energy absorption capabilities. If certain MTBF is adopted as acceptable, then it is possible to select minimum surge arrester energy absorption capability if it does not exceed the allowed MTBF.

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