

Study the Line Length Impact on the Effective of Overvoltage Protection in the Low Voltage Network

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Abstract—The overvoltage protection devices on low-voltage power lines (SPD) are often made using GDA and MOV technology. The selection, proper use and installation of overvoltage protective devices, taking into account the effect of line length and the types of combinations that will affect the protection efficiency, is essential. This paper builds GDA and MOV models with high similarities to the prototype. The evaluation of protection efficiency with different types of coordination and the effect of line length was investigated by simulation-modeling method in simulink environment of Matlab software.

Keywords— GDA (Gas Discharge Arrester), MOV (Metal Oxide Varistor), SPD (Surge Protective Device), Protection Efficiency, Simulink, Matlab.

I. INTRODUCTION

Previous studies have focused on surge protection on low-voltage power lines for equipment with the assumption that lightning impulses directly affect the protective equipment [1, 2]. However, in practice it is necessary to combine protective devices manufactured under MOV technology [3], and the line with characteristics containing capacitance and inductance acting as a surge reduction filter.

Therefore, it is necessary to study the impact of line length on the protection efficiency of the overvoltage protection in the low voltage distribution network under the condition of combining the installation of SPD using MOV technology and GDA technology. The results of the research were tested by the simulation modeling method in Simulink/Matlab environment.

II. GDA MODEL

2.1. Electric Arc Equation between two Electrodes

The GDA model that takes into account the arc appearing between the two electrodes is built as a mathematical model, describing the electrical properties of the arc. This type of model does not simulate complex physical processes within a circuit breaker, but describes the behavioral voltage of GDA. Measurement of voltage and current signals is used to extract differential parameters for

differential equations that describe the non-linear resistance of the electric arc for specific measurements. According to Mayr, the differential equation describing the arc phenomenon between the electrodes of GDA is presented by the expression (1) [4, 5, 6, 7].

$$\left. \begin{aligned} \frac{dx(1)}{dt} &= \frac{u(2)}{\tau} \left(\frac{e^{x(1)}u(1)^2}{P} - 1 \right) \\ y &= e^{x(1)}u(1) \end{aligned} \right| \frac{d \ln g}{dt} = \frac{u(2)}{\tau} \left(\frac{gu^2}{P} - 1 \right) \quad (1) \quad i = gu$$

Where: $x(1)$ is the state variable of the differential equation, and is the natural logarithm of the arc conductivity $\ln(g)$; $x(0)$ is the initial value of the state variable, which is, the initial value of the arc conductivity: $g(0)$; $u(1)$ is the first input variable of the DEE block, this is the arc voltage u ; $u(2)$ is the second input variable of the DEE block, representing the circuit breaking of circuit breaker: $u(2) = 0$ when the contacts of the circuit breaker are closed and $u(2) = 1$ when the contacts of the circuit breaker are open.; y is the output variable of the DEE block, this is the arc current i ; g is the conductance of the arc; u is the arc voltage; i is the arc current; τ is the arc constant of time; P is the cooling energy.

2.2. GDA model

The breakdown voltage is the parameter of the control switch SC (Switch Control). When the voltage applied to the GDA (on the switch K) reaches the value of the breakdown voltage, a time delay is calculated according to

the empirical interpolation formula, corresponding to the gas discharge tube. This value is about 10 -100µs depending on slope of overvoltage (dV/dt).

When the voltage between the two poles of the GDA reaches the value of the breakdown voltage, GDA won't discharge immediately but after a delay, which depends on the slope of the overvoltage.

The burning arc state is simulated under the arc model proposed by Mayr.

The above GDA model is a bipolar device with symmetrical bidirectional characteristics. There is a note that the switch of GDA will not be able to switch to the "off" state when the amperage falls below the value of the current sustained (usually 100mA) or the voltage drops below the generating arc voltage. arc. The equivalent GDA diagram is shown in Fig.1.

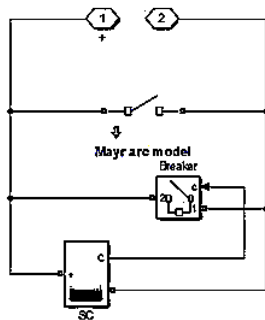


Fig.1 GDA equivalent circuit

2.3. Blocks' Functions

2.3.1. Switch Control (SC) block

The V1 (Voltage measurement) meter measures the voltage between the two electrodes of the gap, and this continuous voltage signal is converted to a discrete signal by the Transfer Fcn unit whose sampling period is 0.001µs. The output voltage signal of the Transfer Fcn block is taken to the absolute value through the Abs block and goes to the comparator block (Compare to Constant) to compare with the breakdown voltage value of the gap, Vb. When the voltage across the gap of the two poles exceeds the value of the breakdown voltage, the output of the Compare to Constant unit will be high and close the Breaker lock. The Breaker lockout signal is passed through a block of time delay (Unit delay) with a time delay of td (Figure 2).

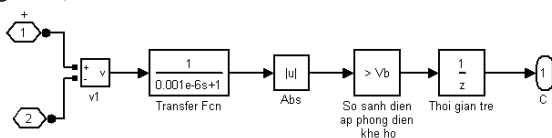


Fig.2 Block diagram of SC lock-off control

2.3.2. Gaps block

The gap block diagram in Figure 3 is considered equivalent to the Breaker block, two resistor elements R1,

Rarc of the model are declared in the Breaker block. The leakage resistance R1 of the gap is 100MΩ declared in the Snubber resistance Rs parameter, the Rarc arc resistance is 2MΩ declared in the Breaker resistance Ron parameter. The Breaker block uses an external control mode (External control mode), the initial state of the lock is the open state (Initial state parameter is zero). Block Breaker Interface (Figure 3).

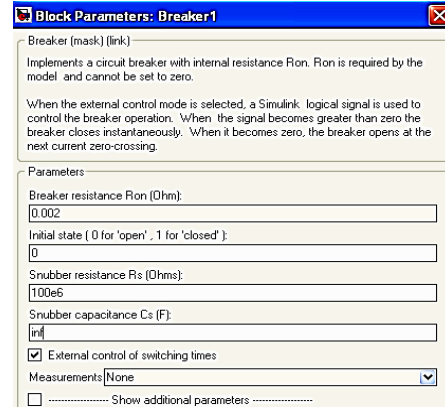


Fig.3 Parameter input interface of the Breaker block

2.3.3. Arc model block

The arc model block is built according to Mayr's proposal (Figure 4).

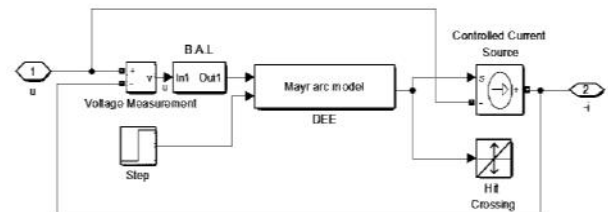


Fig.4 The arc model block was built according to Mayr's proposal

The function of the blocks in the model is as follows: DEE (Differential Equation Editor): the differential equation set-up; Hit Crossing block detects when there is an input signal, in this case it is the current, across the value of 0; Step block is used to control the circuit breaking of the circuit breaker; B.A.L: Gain and integral volume; Voltage Measurement: GDA voltage measuring device between two poles; Controlled Current Source: Source current dependent.

Link the element blocks of the GDA model and establish the interface of the overvoltage protection element model according to GDA technology (Figure 5).

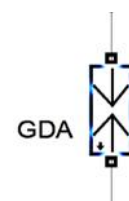


Fig.5 The GDA model interface.

2.3.4. Check the accuracy of the GDA model

To check the accuracy of the proposed GDA model, we simulate a protection voltage value corresponding to the standard impulse 25kA 10/350μs and compare it with the protection voltage value provided by the manufacturer [8]. Circuit diagram of simulation is shown in Fig.6.

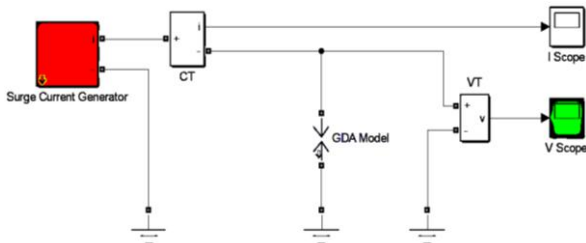


Fig.6 GDA simulation circuit diagram.

By comparing the values of protection voltage through simulation (Vpsim) with the values of protection voltage provided by the manufacturer (Vpcat) which is presented in Table 1. We determine the error protection voltage (ΔV%), this is also an error of the GDA model.

Table 1: Value of protection voltage corresponding to 25kA 10/350μs surge current

Code	I(kA)	V _{pcat}	V _{psim}	ΔV%
DEHNventil M TNC 255	25	1500	1492	0,5
DEHNventil M TNC 255FM	25	1500	1485	1,0

Comment: the proposed GDA model has a high accuracy, the largest error value is 1% and is within the allowed range <5%.

III. MOV MODEL

3.1. MOV's mathematical equation

The mathematical equation describing the relationship V = f(I) of MOV is presented in the expression (2).

$$V = (1 + \text{TOL}/100) \cdot [B_1 \cdot I^{B_2} + B_3] \quad (I > 0) \tag{2}$$

Where: TOL is the threshold voltage tolerance of MOV provided by the manufacturer; the coefficients B₁, B₂ and B₃ are determined by using the MOV V-I curve and the cftool tool of Matlab software.

Table 2: The Bi coefficient values of common MOVs of Siemens Company

Code	V _n (V)	I _s (kA)	V=f(t)
B32K275	275	25	B ₁ =14,93; B ₂ =0,4011; B ₃ =579,2
B40K275	275	40	B ₁ =14,71; B ₂ =0,3962; B ₃ =578,8
B60K275	275	70	B ₁ =16,67; B ₂ =0,3507; B ₃ =573,4
B80K275	275	100	B ₁ =8,282; B ₂ =0,4053; B ₃ =564,5
B32K320	320	25	B ₁ =22,34; B ₂ =0,3847;

			B ₃ =664,7
B40K320	320	40	B ₁ =18,02; B ₂ =0,3935; B ₃ =674,5
B60K320	320	70	B ₁ =12,49; B ₂ =0,4163; B ₃ =680,5
B80K320	320	100	B ₁ =6,729; B ₂ =0,4575; B ₃ =667,7

3.2. The equivalent circuit to MOV model

The MOV model is shown in Fig.7.

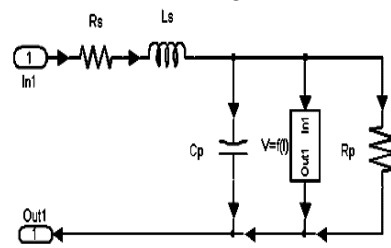


Fig.7 MOV model [9]

With R_S = 100nΩ, R_P = 100MΩ, L_S and C_P have different values for different types of MOV, provided by the manufacturer.

The V-I block diagram of MOV is shown in Fig.8.

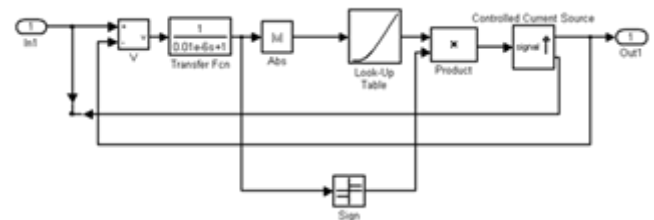


Fig.8 The V-I block diagram of MOV

The V-I relational unit of the MOV element is treated as a controlled current source unit with the current I is a non-linear function controlled by voltage V. The non-linear resistor element uses the voltage measurement block to measure the voltage at the poles of the non-linear element, then passes through the Transfer Fcn block to convert the signal to the discrete from continuous voltage signal with a sampling period of 0.01μs. The output signal is sent to Abs Block to get absolute value and then fed to Look-Up Table block. The Look-Up Table block has the function of looking up the table, for each input voltage value will produce the current value corresponding to the expression (2). The output signal is multiplied by the output of the Signal block (the marker block of the voltage on the 2 poles of the MOV element) and forms the accented current signal. However, this output signal is only Simulink signal, this signal needs to be sent through the controlled current source block to convert into a current signal.

3.3. Check MOV model accuracy

The accuracy of low-voltage MOV element model is determined by comparing the protective voltage value of the MOV element through simulation and the protection

voltage value provided by the manufacturer. Circuit diagram of simulation is shown in Fig.9.

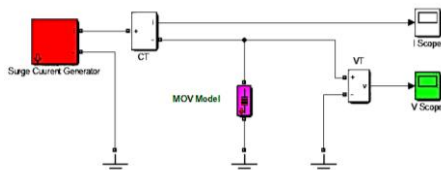


Fig.9 MOV simulation circuit

The result of comparing the value of protection voltage through simulation (V_{psim}) and the value of protection voltage provided by the manufacturer (V_{pcat}) [10] is presented in Table 3. From these data, we determine voltage protection error ($\Delta V\%$), this is also the error of MOV model.

Table 3: Value of protection voltage corresponding to 10kA 8/20 μ s surge current of common MOVs (Siemens)

Code	I(kA)	V_{pcat}	V_{psim}	$\Delta V\%$
B32K275	10	1200	1182	1.5
B40K275	10	1166	1147	1.6
B60K275	10	1000	1001	0.1
B80K275	10	917	919	0.2
B32K320	10	1433	1438	0.3
B40K320	10	1366	1352	0.1
B60K320	10	1267	1262	0.4
B80K320	10	1132	1128	0.4

Comment: Proposed MOV model has high accuracy, the largest error of protection voltage value is 1.6% and is within the allowed range <5%.

IV. LINE LENGTH AND COMBINATION IMPACT ON PROTECTION EFFICIENCY

4.1. Structure of overvoltage protection model

The IEC 62305-4 standard covers over-voltage protection systems and introduces the concept of lightning protection zones (LPZ) to protect against the electromagnetic effects of lightning strikes. It is assumed that a power supply line passing through two protection areas should be protected by an overvoltage protective device. Fig.10 shows the installation location and the different protection levels of overvoltage protection in the low voltage network.

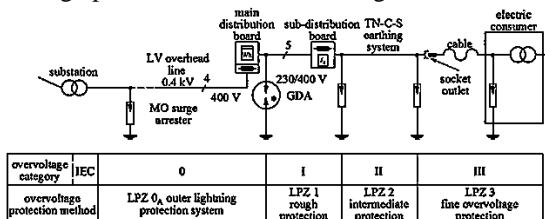


Fig.10 SPD installation location in low voltage network

Surge protective devices corresponding to LPZ0 levels should be able to withstand surge current up to 50kA 10/350 μ s. LPZ1 (GDA) class overvoltage protective

devices should be able to withstand surge current up to 25kA 10/350 μ s. Surge protective devices (MOVs) corresponding to LPZII should be able to withstand surge currents up to 25kA 8/20 μ s. The overvoltage protection device (MOV) of LPZIII level should be able to withstand surge currents up to 5kA 8/20 μ s.

Below, uses the spreading parameter line model to analyze the effect of low voltage line length on GDA operation.

The line parameters per 1km:

- Resistor $R_L=0,471\Omega/km$.
- Inductance $L_L=1521\mu H/km$.
- Capacitance $C_L= 10,39nF/km$.

The test model is a building located in the inner city area. GDA technology overvoltage protection device is located in the main distribution board at the entrance to the building (Cat C). The low-voltage conductor has a cross-section of 70mm², $r_0=0.471\Omega/km$, $L_0=1521\mu H/km$, $C_0=10.39nF/km$. Load consumption has the following parameters: $U_n=230V$, $\cos\phi=0.8$, $I_L=350A$. Calculate $P=112kW$, $Q = 84kVar$. The following, examines the protection efficiency of GDA according to the installation distance to the consumption load.

4.2. Overvoltage protection model with GDA

Circuit diagram of GDA protection efficiency according to installation distance is shown in Fig.11.

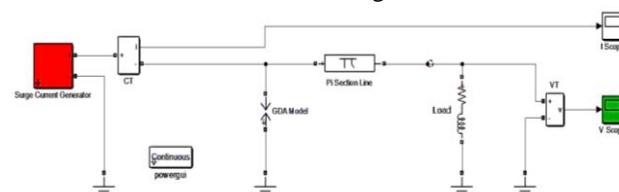


Fig.11 GDA protection simulation circuit

Protection voltage corresponding to surge current 20kA 8/20 μ s with installation distance of GDA $L=1m$ is shown in Fig.12.

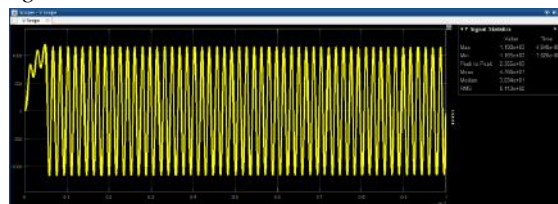


Fig.12 Protection voltage corresponding to surge current 20kA 8/20 μ s with installation distance of GDA $L = 1m$

Table 4: The protection voltage of SPD according to technology GDA with installation distance varying from 1m-5m, corresponding to surge current 20kA 8/20 μ s

L(m)	Protection Voltage V_p 20kA 8/20 μ s
0	1019
1	1190
2	1235
3	1462

4	1610
5	1680

Comment:

- The higher the protection voltage value is corresponding to the longer installation distance.
- The protection voltage value is relatively high even in the case of L = 1m. Therefore, GDA can only protect the electrical equipment.

4.3. Overvoltage protection model with MOV

Circuit diagram of simulating protective efficiency of MOV according to installation distance is shown in Fig.13.

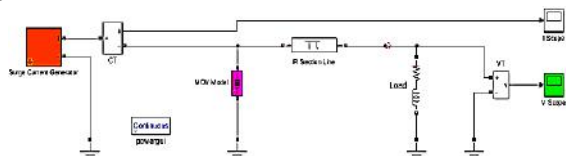


Fig.13 Simulating circuit of MOV protection effect according to installation distance

Protection voltage corresponding to surge current 20kA 8/20µ with installation distance MOV L= 1m is shown in Fig.14.

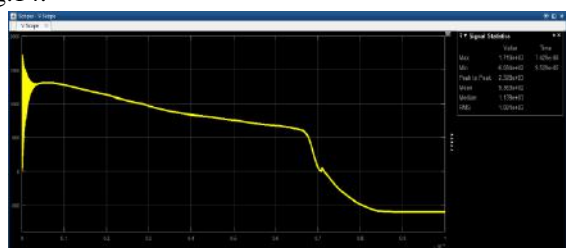


Fig.14 Protection voltage corresponding to surge current 20kA 8 / 20µs for MOV installation distance L = 1m

Table 5: The protection voltage values of the SPD according to MOV technology with installation distance varying from 1m to 5m, corresponding to 20kA 8/20µs.

L(m)	Protection Voltage V_p 20kA 8/20µs
0	1315
1	1719
2	1607
3	1812
4	1928
5	1996

Comment:

- The higher the protection voltage value according to longer installation distance.
- The protection voltage value is relatively high even in the case of L=1m. Therefore, MOV can only protect the electrical equipment.

4.4. Overvoltage protection model with GDA + MOV

The combined circuit diagram of SPD type GDA and SPD type MOV is shown in Fig.15. Here, the SPD type GDA is

installed in the main distribution board and the GDA type MOV is installed in the sub distribution board at 5m, 10m, 15m and 20m distance from the main distribution board.

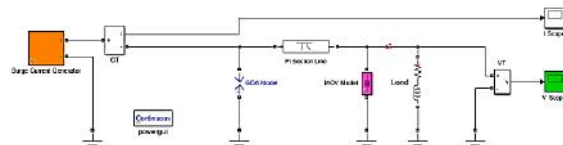


Fig.15 The combined circuit diagram of SPD type GDA and SPD type MOV

The protection voltage corresponding to surge current 20kA 8/20µ is shown in Fig.16.

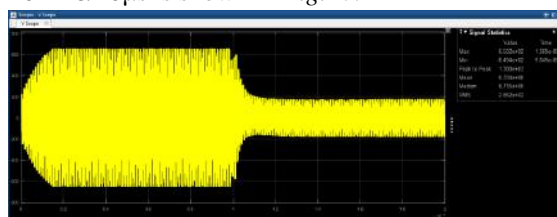


Fig.16 Protection voltage corresponding to surge current 20kA 8/20µs

Table 6: The protection voltage values of SPD according to GDA and MOV technology with the installation distance varying from 5m to 20m, corresponding to surge current 20kA 8/20µs

L(m)	Protection Voltage V_p 20kA 8/20µs
5	735
10	649
15	649
20	649

Comment:

- In the case of combined protection of GDA and MOV, the voltage across the load is much lower than the case of protection with GDA or MOV.
- Protection voltage value varies from 650V to 735V. Therefore, the combined SPD type GDA and SPD type MOV allows to protect the electronic device.

V. CONCLUSION

The paper has proposed:

- Building the SPD type MOV model based on finding V-I relationship by non-linear regression algorithm with the help of cftool tool in Matlab.
- Building the SPD type GDA model, considering the electric arc between the electrodes to improve the accuracy of Spark Gap model.
- Research the protection efficiency of lightning overvoltage protection on low voltage power lines taking into account the line length impact in case of using SPD type GDA, SPD type MOV and the case of combining these two types of SPD.

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