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OVERVOLTAGE DUE TO DISCONNECTED SHORT CIRCUIT AND RE-ENABLEING A DISCONNECTED NETWORK SECTION WITH AUTOMATIC RE-TURNING ON

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Abstract- Considered switching overvoltage when disconnecting a short circuit in the network 110 kV. It was determined that at the initial moment power outages, a voltage surge is observed with a very large amplitude and a very short duration (1 - 1.5 μs), which quickly fades and a post-emergency phase occurs steady state. Impact of value cutoff current to voltage surge amplitude strong, but on the amplitude of the steady-state overvoltage is small. Steady overvoltage does not exceed line voltage. Application of two contact switches reduces these overvoltages only at small cutoff current values (at a resistance value pre-connected resistor close to wave line resistance). A, use of surge arresters completely eliminates splashing voltage and overvoltage does not exceed $2U_{ph}$.

Keywords: Short Circuit, Automatic Reclosing Device, Overvoltage, Surge Resistance, Switching.

1. INTRODUCTION

During the operation of electrical installations, transient over voltages occur when the idle or unloaded line, transformers or a certain part of the system are turned on and off. The causes of such a form of overvoltage are explained by such factors as a residual charge in capacities, multiple ignitions of the arc in switches, and a breakdown of the passing current, the magnetic energy of which is transferred to electrical energy and increases the voltage [1, 2]. Such surges are transient. The values that numerically characterize switching over voltages depend on a number of random circumstances [3]: on the network layout, its mode, its parameters, on the availability of means to combat surges and the effectiveness of these means, as well as on some other factors. Therefore, the quantitative characteristics of switching over voltages turn out to be random values. To limit and reduce the likelihood of high over voltages during switching on and off, there are a number of measures that are divided into two groups - measures to limit the forced component of switching over voltages and measures aimed at weakening the transient component of the switching process [4, 5].

Measures to limit the forced component of switching overvoltage's include: dividing long-distance transmission lines into sections no longer than 250-300 km long with connecting devices to maintain a normal voltage level to intermediate points; use of transformers with adjustable transformation ratio, shunt reactors and synchronous compensators; the choice of such a sequence of connecting the ends of the line, in which the line is first connected to the buses of the most powerful substation, and then to the buses of a less powerful substation. Measures aimed at weakening the transient component of the switching process when the lines are turned on include: installing shunt resistances in switches and synchronously turning on switches, including a resistor in the neutral of the windings of a group of three-phase reactors, as well as installing an arrester [6].

2. ISSUE AND PURPOSE

Disruption of short-circuit currents when they are turned off, which have very large values, greatly affects the formation of over voltages. This last factor has a strong effect when extinguishing short-circuit currents with very large values. An interruption of such a large current, of course, will increase the voltage greatly, which means that it causes large over voltages in the electrical system. If we take into account that the considered section of the network is equipped with an automatic reclosed device, then the opening and closing operation with the same switch will be performed 2-4 times, and it raises a question that how the overvoltage change mechanism will work in this case, this network is required more interest [7, 8].

Although, switching of the AR line occurs less frequently than planned switching on, but may be accompanied by higher over voltages. The main reason for increased over voltages is the presence of a residual charge on the line, which does not have time to drain during the dead time of the automatic reclosure and creates an initial voltage on the line at the moment of switching on [9]. The presented article is devoted to the determination and assessment of over voltages generated during short-circuit opening in electric networks equipped with automatic reclosed devices, as well as their limitation. The scheme of the electrical network under consideration is shown in Figure 1.

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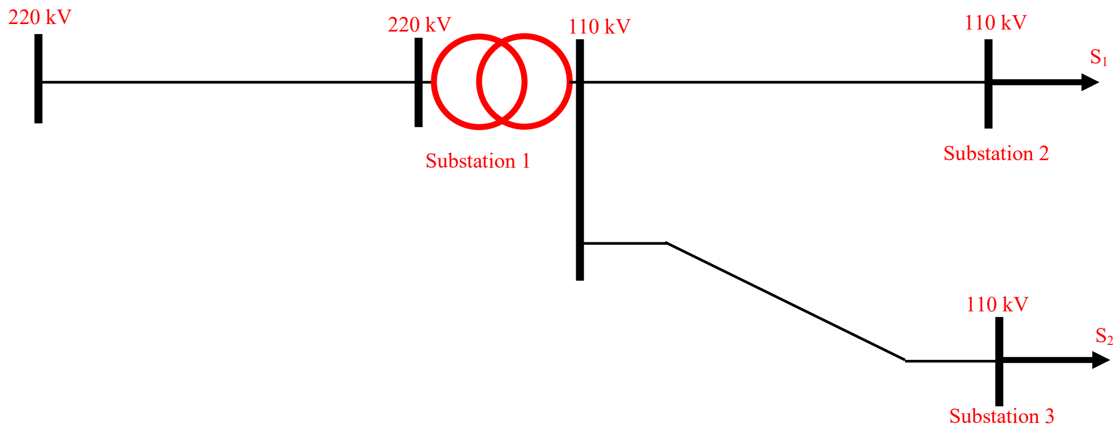


Figure 1. Electrical diagram of the considered network

Substations 1 and 2 with a rated voltage of 110 kV have loads S_1 and S_2, respectively. The occurrence of a 3-phase short circuit in the system bus of 2 substations is considered. The overvoltage that occurred at the beginning and at the end of the line which connected substations 1 and 2 are studied. The purpose of the work is to determine the effect of such a short circuit current on the operation oS_2f load, which is located far from the point of the short circuit current, that is, to determine the radius of propagation of the effect of the short circuit in the network [3].

The calculation is made for the case when the three-phase short circuit occurs at the moment of flowing voltage from one of the phases (in this case, phase A) through its maximum value, which corresponds to the maximum values of the emerging over voltages into the network. Switches that are not equipped with special devices for selecting the moment of switching on receive a command impulse to operate the switching mechanism at an arbitrary moment in time. However, given that tripping near positive or negative voltage maxima usually leads to the highest over voltages, it is assumed that a three-phase fault occurs at the moment when the voltage of phase A passes through its maximum value. The adoption of a short circuit as a three-phase one allows us to consider the process as occurring in a single-phase circuit, which greatly simplifies the calculation [4, 5].

3. STUDY OF THE REPORT

The calculation was made using the algorithmic language OrCAD 17. The calculation results are shown in Tables 1, 2 and in Figures 2-4. Table 1 shows the results of calculations of the normal mode, at the moment of occurrence of a short circuit, at the moments of disconnection of the short circuit by the circuit breaker installed at the end of the line, at the moment of disappearance of the short circuit and at the moment of switching on load 1 using automatic recourse [1].

As can be seen from Table 1, when a short circuit occurs in the low voltage busbar systems of substation 2, the nominal mode current amplitude, which was equal to 103 A, increases to a value of 1645 A. The voltage in the busbar system of this substation drops from 81.92 kV (peak value) to zero, and the voltages in all other parts of the network decrease by more than two times. Relay protection reacts to this short circuit, triggers and disconnects this part of the network.

The switches turn off the short circuit currents usually at the time of passing these currents through their zero value, or with a zero-value close to zero. As noted above, the cutoff of such currents leads to the occurrence of over voltages, and the larger the cutoff current, the greater the overvoltage value. In the calculations, the shutdown of the short circuit was carried out with the zero value of the passing current and with its very small values of equal 3.47 A, 6.94 A, 8.72 A, 14.82 A and 20.83 A. As can be seen from Table 1, the shutdown of the short circuit current with its zero value leads to a small overvoltage (115.511 kV). When the current of the short circuit is equal to 3.47 A, a three-multiple increase in voltage (241.276 kV) is already observed, and a cut of the short circuit of 6.94 A creates an overvoltage with a value of 595.684 kV. The calculation was also carried out for the cases of cutting off the cutoff current equal to 14.82 A and 20.83 A, and for these cases the over voltages obtained have very high values.

Considering that short circuit currents are switched off when they pass zero value or are close to zero value, over voltages corresponding to a cutoff current not exceeding 7A are already dangerous and pose a great threat to the insulation of electrical equipment of a given electrical network. In Figure 2a. overvoltage curves are shown at the end and at the beginning of line 2, as well as at the end of line 3 corresponding to a current cut equal to 6.94 A.

As can be seen from this figure, when the short circuit is turned off, at the end of line 2 (on the contacts of the switch), a voltage surge occurs, the value of which reaches 595.511 kV. The duration of this form of voltage surge is very short, in the range of 1-1.5 microseconds (Figure 2b).

At high cutoff currents, this form of overvoltage has even greater values, and vice versa, at lower values of the overvoltage current, the over voltages decrease. At a zero value of the cutoff current, a voltage surge is not observed (Table 1). This pulse quickly decays and does not even reach the beginning of the line. After the attenuation of this pulse in the network, an emergency steady state occurs, in which at the beginning of line 2 and at the end of line 3 (loads at the terminals S2) there is an increase in voltage to its linear value. There are various ways to reduce switching over voltages. For this purpose, the use of shunt reactors can hardly be considered an economically justified measure of protection.

The use of a non-linear surge suppressor to limit surges is considered as an additional protection measure, since this device only limits surges that occur under unfavorable switching conditions. It should also be recognized that, if possible, with the help of certain protective measures, one should first of all act on the cause of the occurrence of overvoltage's. With this approach, the use of two contact switches with feed-forward resistors can be considered the most suitable way. In these switches, the time between turning on or off the auxiliary and main contacts is approximately 1.5-2 periods of industrial frequency, and this is due to the fact that during this time the transients associated with turning on the auxiliary contacts (or turning off the main contacts) practically extinguish and the closure of the main contacts (or disconnection of auxiliary contacts) is carried out practically in a quasi-stationary mode of the included circuit through a resistor.

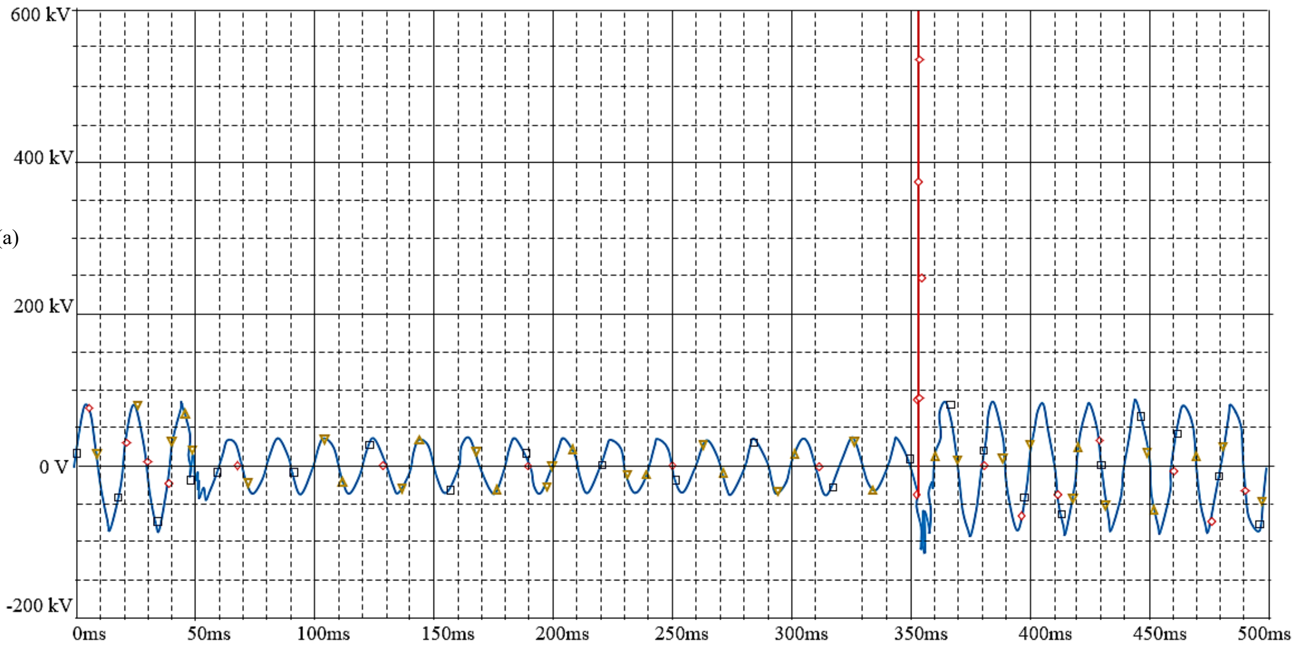
Requirements for the value of the resistor to be switched on are developed on the basis of a joint consideration of the first and second stages of switching on in the presented work, the results of calculations for the case of using two contact switches to reduce overvoltage are shown in Table 2. In the calculations, both contacts of the switch were disconnected at the moment the current passed through the zero value and the resistance of the switch resistor varied in the range of 0-600 Ω.

As can be seen from Table 2, when the value of the resistance of the lead-in resistor is zero, the disconnection of the main contact of the circuit breaker does not play any role in changing the values of the above-mentioned voltages, since the main contacts shunt the branch with zero resistance. Switching off the auxiliary contacts in the absence of a resistor leads to high overvoltage values (as with one-contact switches).

Table 1. Overvoltage in the considered network in its normal mode, when disconnecting short circuit and turning on load 1 using automatic reclosure

Network mode	$I_{s.c}$ kA	Shutdown time switches ms	I_{slice} A	$U_{w2start}$ kV	U_{w2end} kV	U_{n1} kV	U_2 kV
Normal	-	-	-	83.759	81.55	81.55	81.92
Start of short circuit	1.645	t_{sc}=45.169	-	37.357	0	0	36.02
Load 1 disabled		$t_{2\ disable}$=353.197	0	111.427	115.511	0	110.35
Load 1 disabled		$t_{2\ turn\ off}$=353.19	3.47	109.99	241.276	0	108.99
Load 1 disabled		$t_{2\ turn\ off}$=353.182	6.94	111.398	595.684	0	110.32
Load 1 disabled		$t_{2\ turn\ off}$=353.175	8.72	109.907	905.813	0	108.73
Load 1 disabled		$t_{2\ turn\ off}$=353.153	14.82	111.593	1305	0	110.50
Load 1 disabled		$t_{2\ load}$=353.153	20.83	111.684	1880	0	110.33
Disappearance of a short circuit	-	$t_{d.sc}$=500	-	85.409	85.879	0	83.895
Load 1 on	-	$t_{2\ turn\ on}$=677	-	83.683	81.250	81.35	81.944

(a)



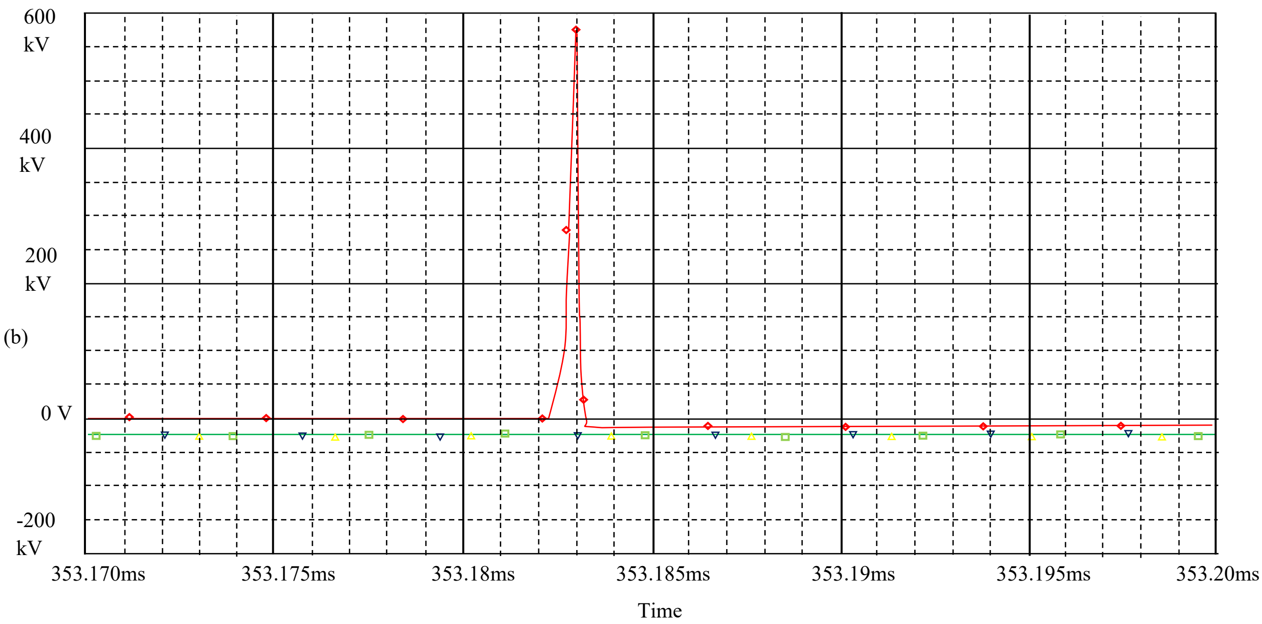


Figure 2. Surge at the end and beginning of line 2, and at the end of line 3 at a cutoff current of 6.94 A, a) surge at the end of line 2 (red), at the beginning of line 2 (blue) and at the end of line 3 (green); b) surge at the end of line 2

By increasing the resistance of the pre-switched resistor, disconnecting the main contacts of the circuit breaker increases over voltages, and disconnecting the auxiliary contacts reduces these over voltages. So, with the resistance of the pre-switched resistor equal to 100 Ω, after disconnecting the main contacts, the overvoltage at the end of line 2 was equal to 59.129 kV, and, after disconnecting the auxiliary contacts, 1124 kV. With the value of this resistance 400 Ω, these over voltages become equal to 78.24 kV and 720.3 kV, respectively (Table 2). These changes of over voltages due to an increase in the resistance of the upstream resistor is maintained up to a value of this resistance equal to 500 Ω. At R=500÷550 Ω, the indicated over voltages become almost equal and this resistance value is taken as optimal, since the over voltages are minimal in this case. With a further increase in the resistance of the resistor, on the contrary, the overvoltage after the disconnection of the main contacts practically does not change, but, after the disconnection of the auxiliary contacts, it increases.

Table 2. Overvoltage in the network under consideration when a short-circuit is switched off with a two-contact

Resistance reactivation resistor	I_{shear}	Open time of breaker		$U_{w2start}$	U_{w2end}	U_{n1}	U_{n2}
		Main contact	Auxiliary contact				
	A	ms	ms	kV	kV	kV	kV
0	0	53.183	-	37.353	0	0	36.68
		353.183	383.246	111.61	2148	0	110.06
100		353.193	-	71.86	59.129	0	70.18
		353.193	391.343	87.94	1124	0	85.93
400		353.211	-	82.40	78.24	0	80.40
		353.211	390.625	88.10	720.3	0	86.03
450		353.201	-	84.42	81.41	0	83.41
		353.201	390.535	88.35	133.14	0	86.33
500		353.193	-	86.46	82.64	0	85.41
		353.193	390.509	87.640	87.950	0	85.54
550		353.193	-	85.940	84.93	0	85.05
		353.193	390.520	86.256	88.400	0	86.16
600		353.193	-	86.57	86.27	0	84.60
		353.193	90.510	89.67	221.79	0	88.27

Thus, as noted above, the optimal resistance value of the resistor is close to the characteristic impedance of a power line of a given voltage class. Indeed, with an infinite source power, the inclusion of an overhead line through a resistance equal to the wave resistance practically does not lead to the creation of a transient process, since the reflection coefficient from the resistance will be equal to zero [8, 9].

Overvoltage curves at the end and at the beginning of line 2, as well as at the end of line 3 with a pre-connected resistor of 400 Ω are shown in Figure 3. As can be seen from this figure, with the disconnection of the main contacts, the overvoltage at the beginning of line L2 increases from 37.353 kV to 82.4 kV, and at the end of line L2 are from zero to 78.24 kV.

With the disconnection of the auxiliary contacts at the beginning of line L2, the overvoltage value of 82.4 kV increases to a value of 88.1 kV, and at the end of this line a voltage surge appears, the value of which reaches 720.3 kV and this value drops very quickly to a value of 88.1 kV. Overvoltage curves at the end and at the beginning of line 2, as well as at the end of line 3 with a pre-connected resistor of 400 Ω are shown in Figure 3. As can be seen from this figure, with the disconnection of the main contacts, the overvoltage at the beginning of line L2 increases from 37.353 kV to 82.4 kV, and at the end of line L2 - from zero to 78.24 kV. With the disconnection of the auxiliary contacts at the beginning of line L2, the overvoltage value of 82.4 kV increases to a value of 88.1 kV, and at the end of this line a voltage surge appears, the value of which reaches 720.3 kV and this value drops very quickly to a value of 88.1 kV.

4. COMPARISON OF CALCULATION RESULTS

Comparison of the results of calculating the short circuit trip (for the case *I_cut* = 0) by conventional (single-contact) and two contact switches show that when using two contact switches with a pre-switched resistor, the resistance of which is equal to the wave resistance of the power line, over voltages in the network have the lowest values, especially at the end of the line, where the short circuit occurs. According to the calculation results, when using conventional switches at the end of line L2, the overvoltage is 115.511 kV, and when using two contact switches, 87.95 kV. As you can see, decrease is significant.

The voltage drops at the beginning of line L2 and at the end of line L3 is also significant. When the short circuit is turned off by conventional switches, these over voltages reach values almost equal to the line voltage (111.427 and 110.35 kV), and when the short circuit is turned off by two contact switches, 87.64 and 85.54 kV. As you can see, when using two contact switches, over voltages practically do not occur. In this work, we also consider the case of limiting this form of switching overvoltage using surge arresters, which are usually connected to the substation HV busbar system. The results of this calculation are shown in Figure 4, which shows the voltage curves at the end of line L2 (green curve), at the beginning of this line (red curve) and at the end of line L3 (blue curve). As can be seen from this figure, at a cutoff current value of 6.94 A, a voltage surge occurs at the end of line L2 with an amplitude of 160.991 kV, and at a cutoff current of 20.83 A, with an amplitude of 161.496 kV. An increase in the cutoff current by almost 7 times practically does not change the amplitude of the overvoltage surge. Presence in busbar systems of surge arresters' limits overvoltage to $2U_{ph}$. In conclusion, we note that, to protect against over voltages that occur during automatic reclosing of lines, all of the above listed means are used: measures to limit the forced component, shunt resistances in switches, synchronous line switching, as well as arresters and surge arresters.

5. CONCLUSIONS

1. When the short circuit is turned off, the value of the cutoff current strongly affects the resulting over voltages, in which the voltage in network becomes equal to linear value. Duration especially at point of current breakdown. The overvoltage at this point increases abruptly, having the form of a surge and quickly decays. Then it occurs after an emergency steady state, in which the voltage in the network increases to a linear value. The duration of the burst is very short, 1-1.5 μs.
2. The use of two contact switches with an upstream resistor with a resistance equal to the characteristic impedance of the power line limits this overvoltage to their linear values.
3. Changing the value of this resistance from the value of the wave resistance of the power line in one direction or the other increases the overvoltage when the short circuit is turned off.
4. When re-closing the line through automatic reclosure, there is practically no overvoltage arise.

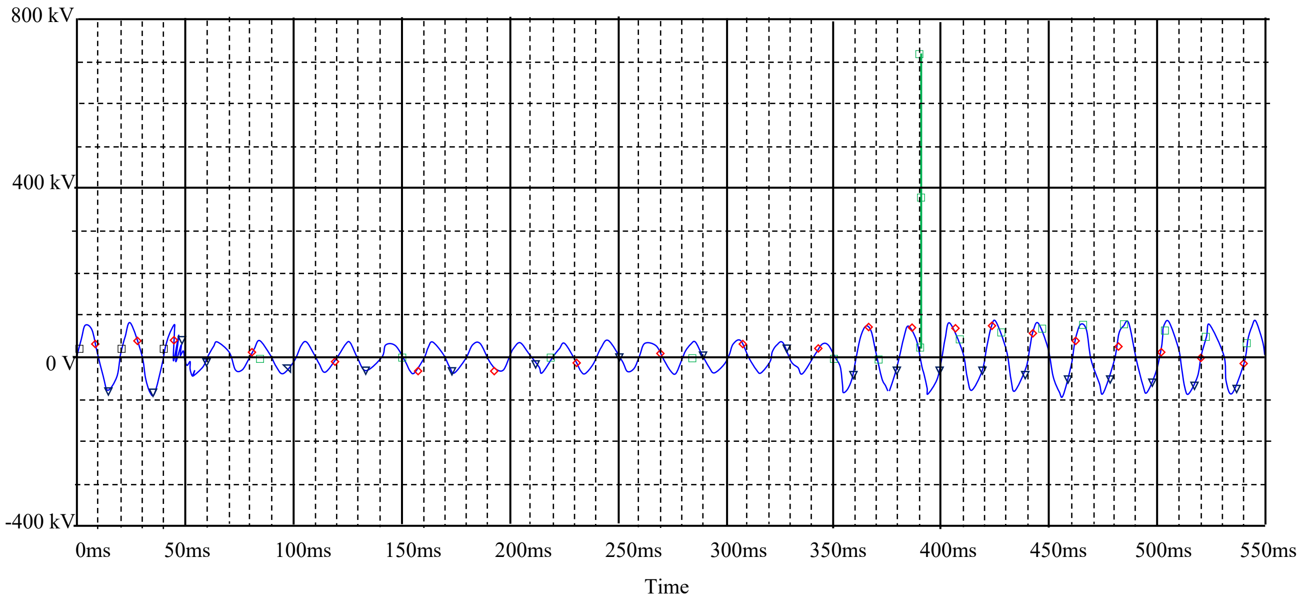


Figure 3. Overvoltage at the end and at the beginning of line 2, and at the end of line 3 when using a two-contact switch with the resistance of the upstream resistor is 400 Ω, green: at the end of line 2, red: at the beginning of line 2, blue: at the end of line 3

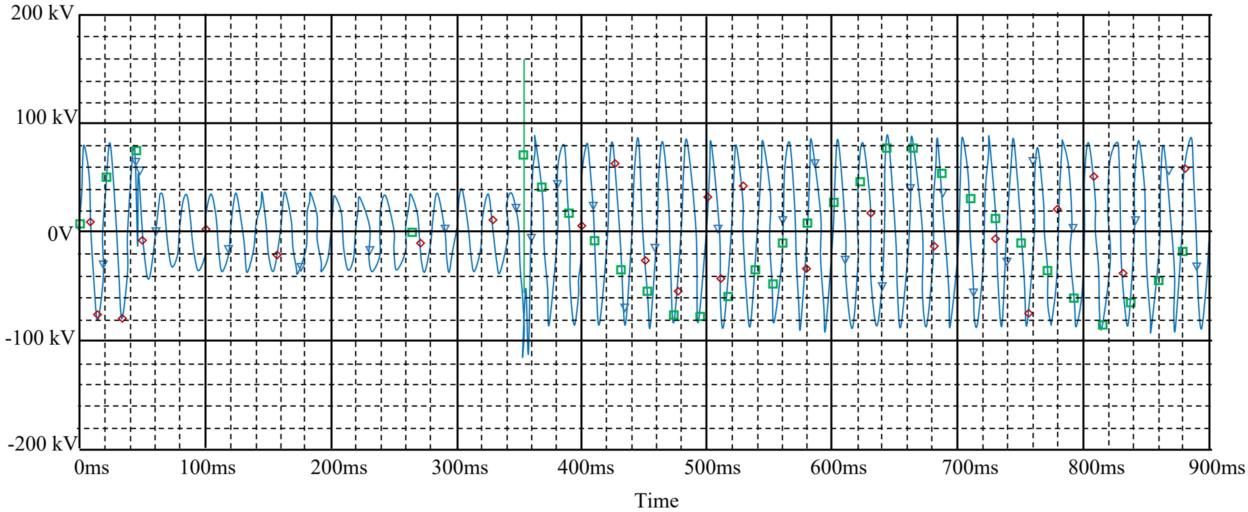


Figure 4. Surge at the end and at the beginning of line 2, and in end of line 3 when using surge arresters. overvoltage at the end of line 2 (green), at the beginning line 2 (red) and at the end of line 3 (blue)

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