CONTROLLED SWITCHING – SOLUTION FOR REDUCING THE OVERVOLTAGES AT COMMUTATION OF THE TRANSPORT AND DISTRIBUTION LINES

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ABSTRACT

Recently, worldwide, the controlled switch became a technical solution for reducing the switching stress. After 90es, the number of equipment which uses the controlled switch fast increased, mainly due to the achieved performances.
The controlled switching can be applied to any type of commutations. Now there are dedicated controllers which are used more often for the switching of the transport and distribution lines, of the small inductive loads, of the capacitors batteries, or the energizing the no load power transformers. The paper deals with the simulation of the commutation of a transportation line by using the distributed parameters model. The controlled switch of the line is compared with the uncontrolled one, highlighting the major differences in what concerns the stress.

TRANSPORT AND DISTRIBUTION LINES SWITCH

When the long lines are energized, undesired over voltages can be generated in the transport and distribution networks. These are caused by the propagation, reflection and refractions of electromagnetic waves, both in ramifications points and end of the lines. Such phenomenon both occur when the lines are quick re-energized after a disconnection. The cause of the over voltages in this case are the residual charges on the line. As will be seen, both the over voltages and their slopes determine important stress of the equipment insulation.
When connected, at the end of the long lines over voltages can occur due to more causes. For lines shorter than 1500 km, the input impedance has capacitive character and the voltage drop on the equivalent inductive reactance of the system has the same sign with the supplying fem. Consequently, this voltage drop is added to the fem. Thus, the resulted overvoltage highly depends by the line length and by the short circuit power of the system.

Another cause of the over voltages resides in the oscillations which occur when the initial repartition of the voltage across the line is replaced by the new repartition corresponding to the new steady state operation, after its connection.
The stress of the insulation depends both by the amplitude of the overvoltage and by its shape, characterized by two parameters: rising duration and falling duration. (Gusa 2002).
The mathematical models used to determine the over voltages can be more or less complex, depending on the characteristics of the studied commutation phenomenon. The long lines can be modeled by circuits with either uniform distributed parameters or concentrated parameters. The models can be single phase or three phase ones.
The over voltages when a line is energized can be analytically estimated if two hypotheses are considered: the lines have no losses and all the three phases of the breaker are simultaneously connected.
For the analytically evaluation of the over voltages at the line energizing with no residual charge on the line, the simplified diagram in Figure 1 can be considered.
The equation specific to the equivalent electric system is:

$$e_s = u_1 + L_s \cdot \frac{di_1}{dt}. \tag{1}$$

The equations specific to the uniform distributed long line model are:

$$-\frac{\partial u}{\partial x} = r \cdot i + L \cdot \frac{\partial i}{\partial t}, \tag{2}$$

$$-\frac{\partial i}{\partial x} = g \cdot u + C \cdot \frac{\partial u}{\partial t}, \tag{3}$$

where:
- e_s – the instantaneous value of the fem of the system;
- u_1 – instantaneous voltage at the front end of the long line;

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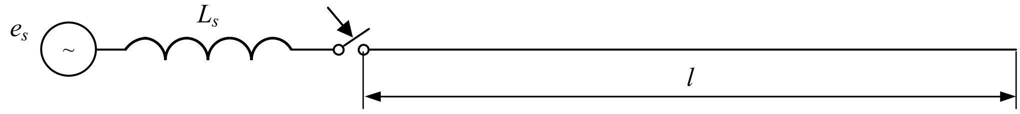

Figure 1: Simplified Equivalent Diagram of a No Load Line when is Connected

- i_1 – the instantaneous value of the current at the front end of the long line;
- L_s – the inductance of the supplying electric system;
- u, i - the voltage and the current in a point of the line;
- r, L, g, C – the parameters of the line per length unit.

By solving the equations (1-3), the voltage at the end of the line results:

$$u_2(t) = B \cdot \sin(\omega t + \alpha) - \\ -\sum_{k=1}^{n} B_k \cdot \cos\left(\omega_k t - arctg\left(\frac{\omega}{\omega_k} \cdot ctg\alpha\right)\right), \quad (4)$$

where

ω_k are the roots of the equation (5)

$$\text{ctg}\,\tau\omega_k = \frac{L_s \cdot \omega_k}{Z_c}, \quad (5)$$

$$B = \frac{E_m}{\cos\tau\omega - \frac{L_s \cdot \omega}{Z_c} \cdot \sin\tau\omega},$$

$$B_k = E_m \cdot \frac{\omega_k^2}{\omega_k^2 - \omega^2} \cdot \frac{1}{\cos\tau\omega_k + \frac{\tau\omega_k}{\sin\tau\omega_k}},$$

α is the phase of the source voltage at the connection instant.

For the front end of the line results the following expression of the voltage

$$u_1(t) = B \cdot \sin(\omega t + \alpha) \cdot \cos\omega\tau - \\ -\sum_{k=1}^{\infty} B_k \cdot \cos\omega_k\tau \cdot \cos\left(\omega_k t - arctg\left(\frac{\omega}{\omega_k} \cdot ctg\alpha\right)\right),$$

B and B_k being the same as in (4).

The obtained expressions of the voltages at the front end and at the end of the long lines show that the maximum overvoltage factor at the end of the line is greater than 2 and also greater than the factor at the front end of the lines.

The over voltages can be reduced by using breaker with pre-insertion resistance or by using variable resistance dischargers.

An intelligent method for avoiding the over voltages when transport and distribution lines are re-energized is the using of the controlled switch. The method is based on the control of the difference between the source voltage and the residual voltage on the line. The re-closing command is supplied at the instant when this difference is minim. In this case, the over voltages will have the same values as when the line with no residual charge is connected. The breaker must have the facility to control independently each pole. This is the case studied further.

MATLAB SIMULINK MODEL FOR CONTROLED SWITCH OF THE TRANSPORT AND DISTRIBUTION LINES

The model of the distributed parameters long line was the one available in the SimPowerSystems of Matlab.

The Distributed Parameter Line block implements an N-phase distributed parameter line model with lumped losses. The model is based on the Bergeron's traveling wave method used by the Electromagnetic Transient Program (EMTP) (Dommel 1969).

In this model, the lossless distributed *RLC* line is characterized by two values (for a single-phase line): the surge impedance $Z_c = \sqrt{\frac{L}{C}}$ and the phase velocity $v = \sqrt{\frac{C}{L}}$. The model uses the fact that the quantity $u+Zi$ (where u is line voltage and i is line current) entering one end of the line must arrive unchanged at the other end after a transport delay of $\tau = l / v$, where l is the line length. By using the current injection method of SimPowerSystems, a two-port model was derived.

For multiphase line models, modal transformation is used to convert line quantities from phase values (line currents and voltages) into modal values independent of each other. The previous calculations are made in the modal domain before being converted back to phase values. In comparison to the PI section line model, the distributed line represents wave propagation phenomena and line end reflections with much better accuracy.

The Simulink model of the simulated lines is the one depicted in Figure 2.

For comparison, two identical lines were considered, one switched uncontrolled and the other with control of the re-closing instant. Each of them is switched by a breaker. For both of them, the moment of the opening is the first zero crossing of the current after the opening command was applied. The uncontrolled breaker is reclosed at a given time. The re-closing occurs instantaneously.

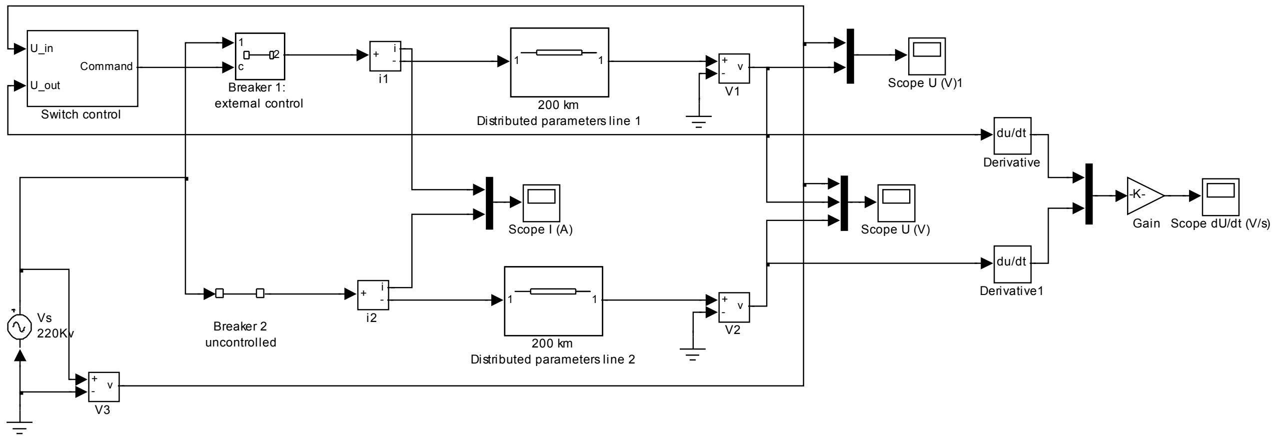

Figure 2: The Simulink Model for the Two Types of Switching

The breaker corresponding to the controlled switch line is reclosed by controlling the difference between the source voltage and the residual voltage on the line. Its reclosing command, given arbitrarily, is validated and applied only at the first instant when this difference is minim. The dialog boxes of the two breakers are depicted in Figure 3.

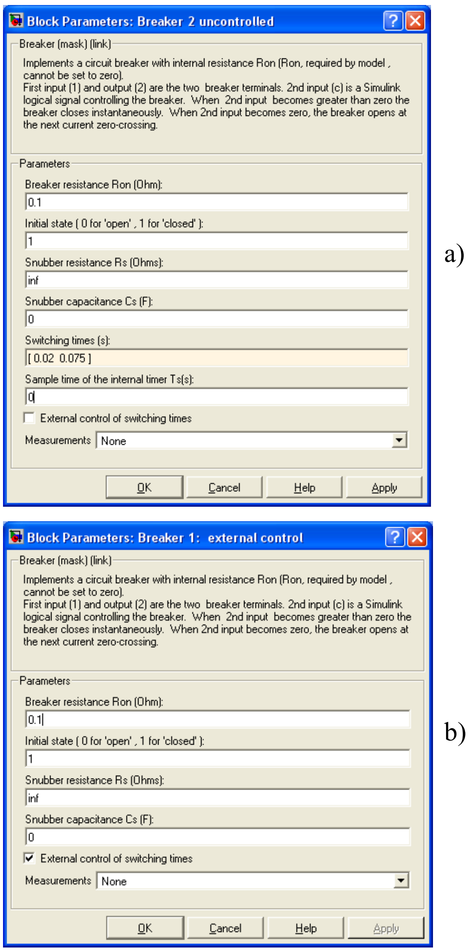

Figure 3: The Dialog Boxes of the Uncontrolled Switch (a) and of the Controlled one (b)

The simulation was run for a long line having the following parameters:

- length = 200 km;
- resistance per unit length $R = 0.0339\ \Omega$/km;
- inductance per unit length $L = 1.04{\cdot}10^{-3}$ H/km;
- capacitance per unit length $C = 1.089{\cdot}10^{-8}$ F/km;
- supplying voltage = 220 kV.

For controlling the re-connection instant, a Simulink block *Switch control* was created which issues the external command for Breaker 1 (Ivanov 2007). This block, Figure 4, monitors the absolute value of the difference between the supplying voltage and the voltage at the end of the line. When this difference is minimum (detects the tendency to increase), the external command is validated and delivered as output to the breaker, which at its turn, switch on instantaneously.

The command for opening the breaker is not synchronized with the circuit state. The breaker opens at the first zero crossing of the current after the turn-off command.

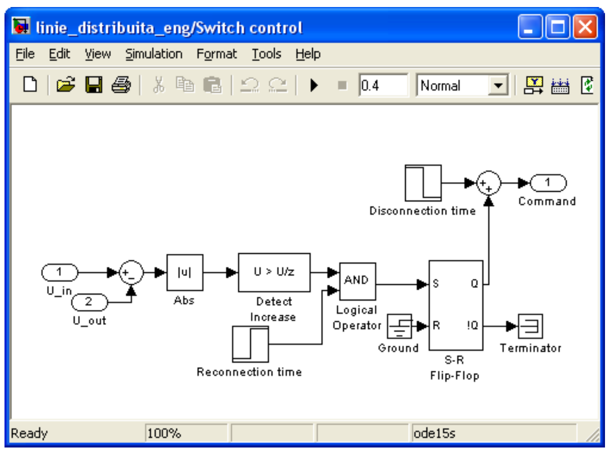

Figure 4: The Switch Control Block

By the dialog box of the block, Figure 5, the disconnection and re-connection instants can be specified. The reconnection itself occurs at the first minimum of the difference between the supplying voltage and the voltage at the end of the line, after the reconnection time specified in the dialog box.

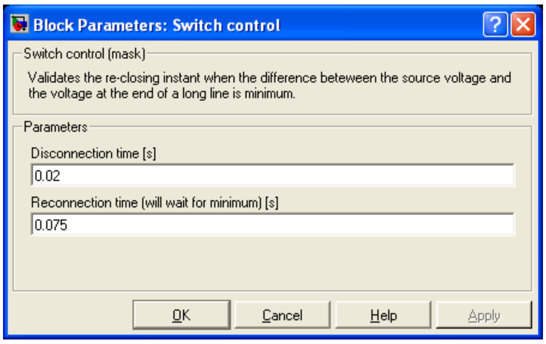

Figure 5: The Dialog Box of the Switch Control Block

SIMULATIONS RESULTS

The simulation of the reconnection of the two lines (uncontrolled – Line 2 and controlled one – Line 1) was performed for similar conditions: disconnection command at 0.02s and reconnection command at 0.075s. The disconnection of the both lines occurs at the first zero crossing of the current after the command instant (0.025s as can be seen in Figure 6).

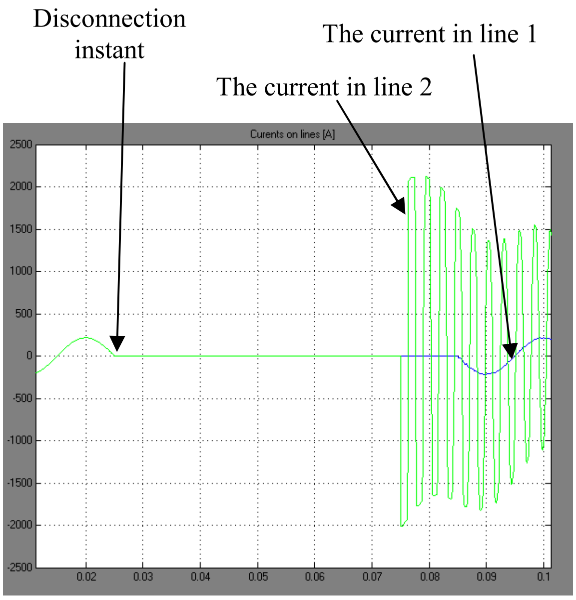

Figure 6: The Currents in the Two Lines

The reconnection is instantaneously for the Breaker 2 (uncontrolled) when the command is issued (0.075 s). The reclosing of the controlled breaker is delayed until the minimum of the difference between the supplying voltage and the voltage at the end of the line occurs (Figure 7).

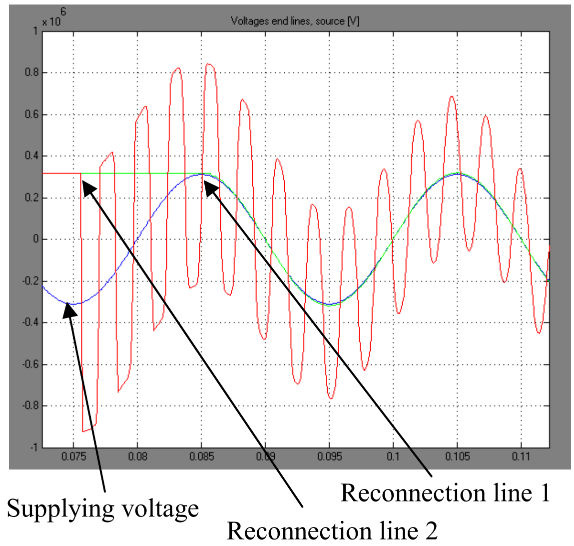

Figure 7: Reconnection instants

As can be seen both in Figure 8 and the detail from Figure 7, the overvoltage at the end of the uncontrolled line is quite important (overvoltage factor 2.73). On the controlled switch line the overvoltage is almost null, the voltage at the end of the line being practically identical with the supplying voltage (Figure 7).

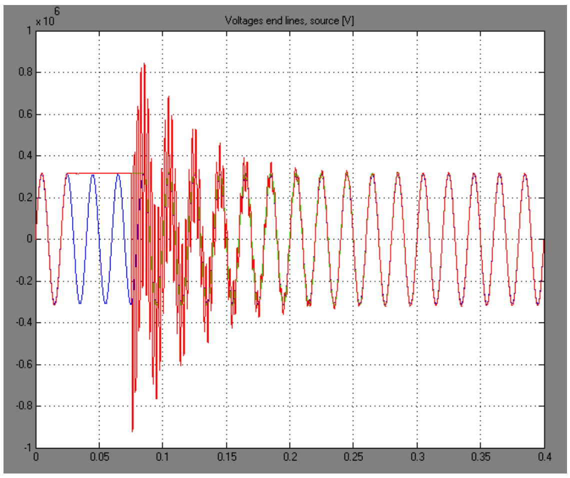

Figure 8: Voltages at the end of the lines after reconnection

The processes at the reconnection determine high stress of the insulation. In Figure 9 is plotted the slope of the voltage at the end of the two lines. As can be seen, the stress of the uncontrolled line reaches more than 12,000V/µs. For the controlled switch line the stress is almost absent, as can be seen in the detail plotted in Figure 10.

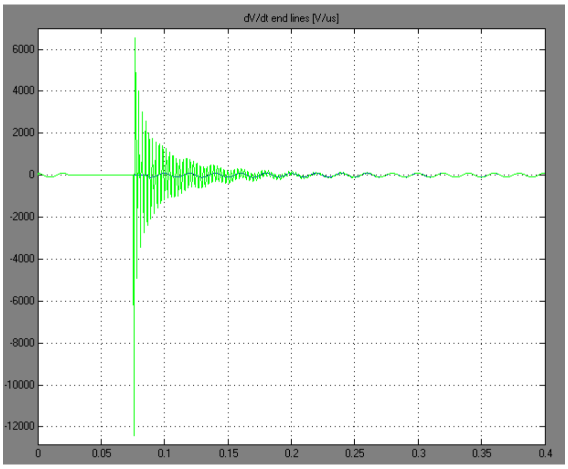

Figure 9: The slope of the voltage at the end of the reconnected lines

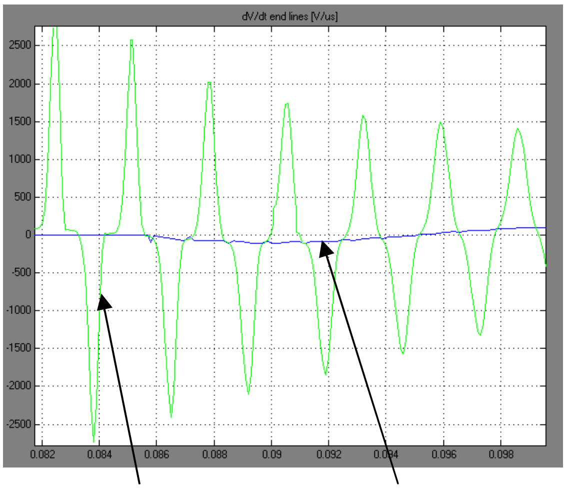

Figure 10: Detail of the slope of the voltage at the end of the reconnected lines

CONCLUSIONS

The paper analyzed the stress which occurs at the reconnection of the long lines. If no measures are carried out, the overvoltage and the corresponding voltage slope at the end of the line rich dangerous values.

If the switch-on process is controlled and synchronized with the minimum of the difference between the supplying voltage and the voltage at the end of the line, the additional stress is almost inexistent. Such control must be performed on each pole of the breaker.

In practice, the control of the reconnection must take into account the delay introduced by the beaker actuation mechanism, specific for each type of mechanism. This delay is at its turn, dependent on the pause time after the last actuation, on the ambient temperature and on the total number of actuation maneuvers done during the life time.

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