Monitoring System for Reducing the Electric Equipment Stress in Transport and Distribution Lines

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***Abstract* – A frequently used method for monitoring and fault diagnosis of the electric equipment is the one based on the analytic model. The paper applies the diagnosis method based on the analytic model by investigating the waveforms of the currents and voltages specific to a transport and distribution line when interruption fault occurs. This method can be used when the system behavior is compared with the results of the mathematical model which reproduces the system in normal operation conditions. For identifying the fault, the waveforms corresponding to different faults are stored in an information database and compared with the ones corresponding to the normal operation. The paper presents a microcontroller based system used to control switching of interruption fault for transport and distribution lines. In order to reduce the breaker stress due to the commutation overvoltage, the paper presents an analysis of the optimum instant when a long line must be disconnected. Similarly, an analysis is performed on the instants of the long lines reconnection. The both analyses are performed taking into account the specific parameters and the length of the lines. The focused magnitudes during the transients are both the maximum values and the slopes of the overvoltage and the maximum values of the currents.**

Cuvinte cheie: *monitorizare, diagnoză defect, linii aeriene lungi, defect de întrerupere, sistem cu microcontroler.*

Keywords: *monitoring, fault diagnosis, overhead long lines, fault interruption, microcontroller system.*

I. Introduction

The diagnosis of the systems can be defined as the assembly of the scientific exact and heuristic methods for investigating, diagnosis, modeling and design, applied for improving the quality of the decisions that determines the efficient control of a system. This aim is possible only if several stages, which determine the life cycle of the system, are fulfilled (Fig. 1).

The methods for faults detection and diagnosis can be classified in three groups:

- methods based on analytic models
- methods based on signals.
- methods based on knowledge.

The methods based on analytic models consist in comparing the system behavior with the results of the mathematical model that reproduce the system in normal operation. If the analytic model is available, this method proves to be more efficient than the methods based on signals [1].

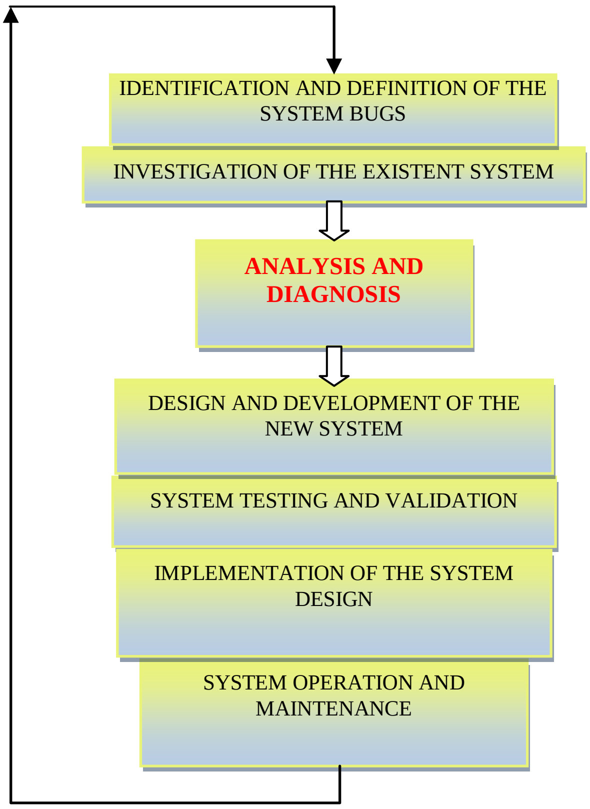

Fig. 1. The life cycle of a system.

The methods based on signals select the signals which contain information and data specific to the fault operation from the multitude of the signals measured from the process. By analyzing the selected signals, the possible symptoms of the faults are defined, the faults are located, the moment of occurrence and possible causes are identified also [2].

The methods based on knowledge are used when the complex systems must be diagnosed. In these cases, the knowledge about process can be often insufficiently. The behavior of the system is quantitatively described by using knowledge about system that is grouped in rules and facts, as results of human empirical observations. For the complex systems, the qualitative models can be used for defining the relationship cause-fault-symptom by using the fault tree concept [3].

In power system, different types of faults can occur which influence the normal operation of electric equipment. The most often and dangerous ones are the short circuits. The short circuits can be: phase to phase short circuits: two or three phases with different behavior if the system is three or four wires; phase to ground short circuits: single, double or triple.

The main causes of the short circuits are: the puncture or the surface flash over of the line electrical isolators or of the disconnections' because atmospheric over voltages; wrong maneuvers performed by the operating personnel; the depreciation of the lines isolation parameters due to external conditions (presence of chemicals, humidity, pollution etc.); the mechanical stress of the pylons and lines due to the wind or precipitations etc.

II. The Hardware Architecture System

For monitoring the voltages at the end of the long lines, an experimental system based on a microcontroller was developed. The results are displayed in real time by a graphic user interface. If a fault occurs both disconnection and reconnection of the line will be performed in a controlled manner.

The experimental system implies two main parts: hardware (sensors, transducers, A/DC, serial transmission) and software (field module programming, transmission protocols, user interface) [4].

The hardware part of the system is centered on microcontroller DS87C550. This type of micro-controller is code fully compatible with the 8051 family microcontrollers, being equipped with many integrated peripherals that make it suitable for embedded applications. More than that, being equipped with the high speed core specific to the Dallas micro-controllers, the performances achieved by the hardware subsystem based on this module make it very suitable for the on-line monitoring of the high speed electrical equipments.

The acquiring and transfer module consists of the blocks: Sources, Controller, Local console, Inputs, Outputs and Serial communication interface (Fig. 2). By the way of three precise voltage regulators, the Sources block supplies the regulated voltages to the micro system. The Controller block is the core of the module and consists of the controller itself, the full duplex RS485 serial interface, connector to the 7 digits display, digital open collector output that can be used for commanding a power element (relay), non-volatile serial EEPROM.

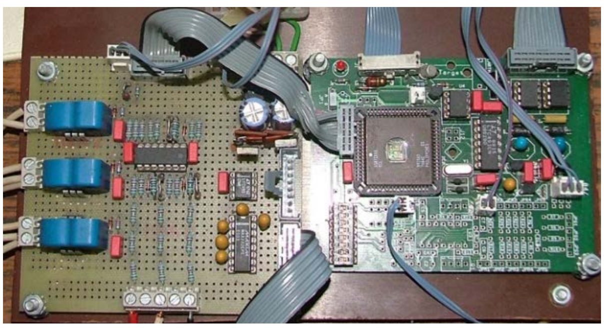

Fig. 2. The microcontroller system.

The experimental system monitors the voltages at the end of the high voltage overhead lines during the transients determined by the lines commutations.

If a fault occurs, the commutations of the transport and distribution lines will be performed in a controlled manner, in order to reduce the commutation over voltages. The same controlled switching will be applied for the lines reconnections.

III. The Commutation of Transport and Distribution Lines

A. Connection of overhead long lines

The analytical analysis of the over voltages when no load long lines are switch-on was presented in [5].

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, in p.u., and also greater than the factor at the front end of the lines. The optimal instant for controlled switching-on of a no load line is the one when the voltage across the breaker crosses zero.

An intelligent method for avoiding the over voltages when transport and distribution lines are re-energized is the using of the controlled switch [6]. 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[7,8].

B. Disconnection of overhead long lines

The current drawn from the source by the no load long lines have a capacitive phase. Consequently, at the zero crossing of the current, the phase voltage will be not null and closer by the peak value of the source as the load is more reduced. When a long line is disconnected, after the separation of the contacts, the line capacity will rest charged with the voltage corresponding to the separation instant.

For shorter lines (less than 400 km) it can be assumed that the residual voltage is practically constant. On the other hand, in real long lines, oscillations occur caused by the potential difference between the two ends of the line at the disconnection instant.

Analyzing the voltage at the end of the line results it results that the transitory over voltage factor at the end of the line is, in p.u., greater than 2 and is greater than the one at the front end of the line. If we take into account the transient over voltage which is greater at the end of the line than at the front end, significant values for the over voltage factor can result (3.5 in p.u.). In order to rest within the insulation class, special over voltages protections must be considered [9, 10].

The most usual protections are based on oxide-metal dischargers together with discharging resistors. The method is quite reliable, but the costs are large.

Another way to limit the over voltages is the use of breaker with fast dielectric rigidity recovery. This type of breakers does not allow the re-ignition of the electric arc.

The same behavior have the breakers with pre-insertion resistor.

The very modern solution for reducing the dielectric and thermal stress of the breakers which operates long lines is the controlled switch.

The first solutions applied for the long lines controlled switch did not have positive outcomes because the resulted overvoltage was greater than the insulation class. The explanation was assigned to command errors. The most frequent errors were caused by the dependency of the breaker switching time vs. the pause time. The modern controllers can compensate the breaker pause time and are able to achieve the severe conditions specific to the long lines commutations.

The controlled switching-off increases the electric arc extinguishing capacity, without re-ignition. This method is advantageous even for the modern breakers which generally have small probability of re-ignition. In order to have minimum voltage over the breaker, the units with fast dielectric rigidity recovery are preferred. In addition, the pause time compensation is essential for all the breakers whose switching times depend on the driving mechanisms pause time.

IV. MATLAB SIMULINK MODEL OF THE OVERHEAD LINES

The model of the distributed parameters long line was the one available in the SimPowerSystems of Matlab [11] (Fig.3).

The simulation was run for a long line having the following parameters [12]:

- length l = 200 km;
- resistance per unit length $R = 0.07451\ \Omega$/km;
- inductance per unit length $L = 1.2945\cdot10^{-3}$ H/km;
- capacitance per unit length $C = 8.8\cdot10^{-9}$ F/km;
- supplying voltage U = 220 kV.

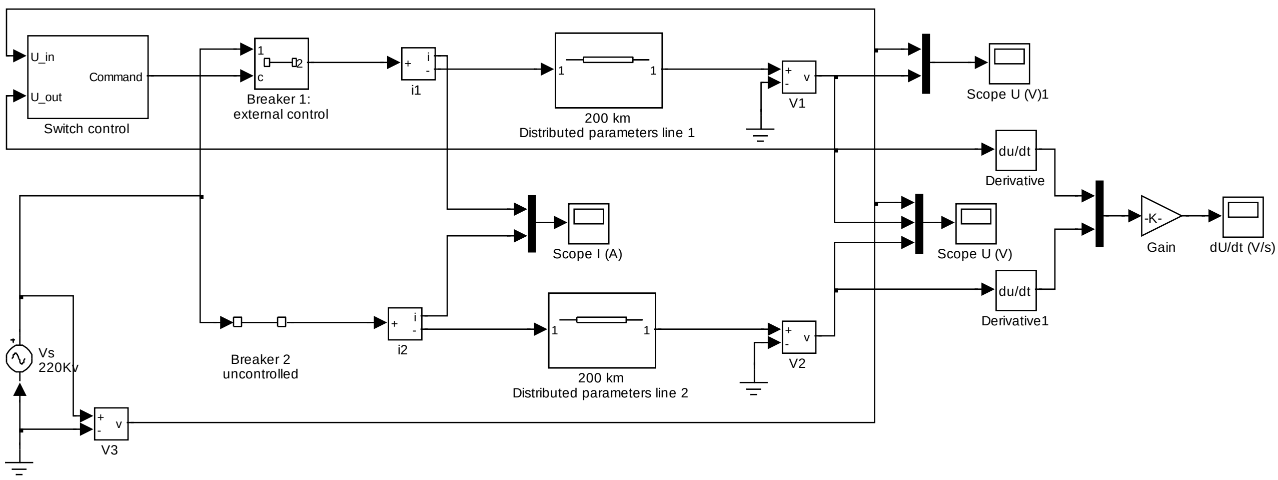

Fig. 3. The Simulink model of the long line.

For controlling the re-connection instant, a Simulink block Switch control was created which issues the external command for Breaker 1. This block 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, the external command is validated and delivered as output to the breaker, which at its turn, switch on instantaneously.

V. SIMULATIONS RESULTS

The simulation of the reconnection of the two lines (controlled one – Line 1 and uncontrolled – Line 2) was performed for similar conditions.

A. The influence of the switching time on the electric equipment dielectric stress

The overvoltage's which occur at the end of long lines due to their reconnections can be reduced by controlling the instant of the reconnection. If the reconnection is executed at the zero crossing of the source voltage, the reconnection overvoltages are much reduced: 500kV instead of 900kV if the reconnection is executed when the source voltage reach its maximum (Fig. 4). It can be noticed that the voltage at the end of the long lines re-attain the source voltage only after about 0.2s (Fig. 4).

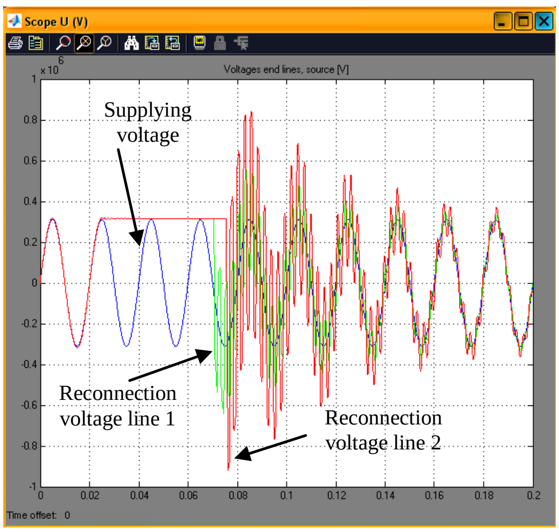

Fig. 4. Voltages at the end of the two lines and the source [V].

In the same time, the electric equipment dielectric stress become dangerous due to the very high dV/dt slope of the commutations overvoltage's (Fig.5).

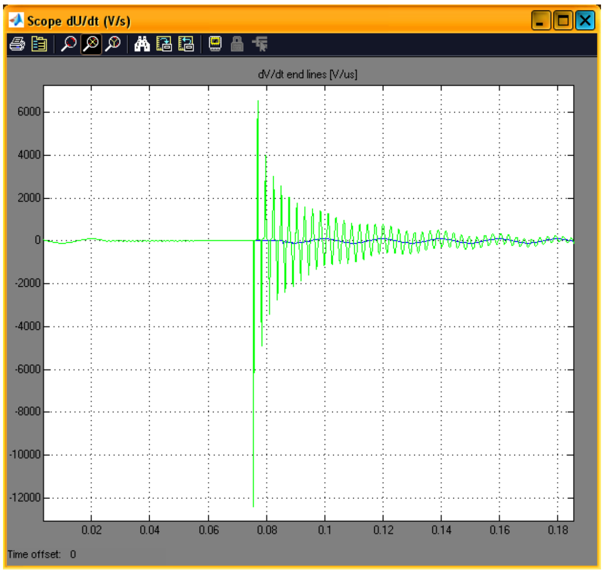

Fig. 5. Overvoltage's slope (dV/dt) at the long lines end.

If the reconnection is executed at a random instant, the over voltages can achieve any value between 500kV and 900kV (Fig.6).

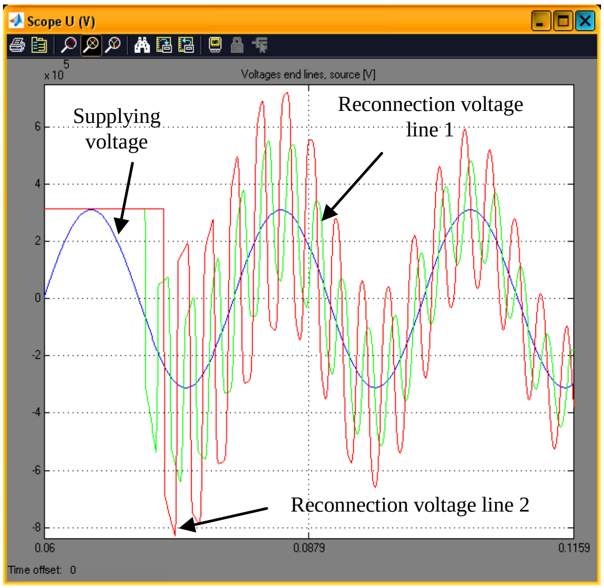

Fig. 6. Voltages at the end of the two lines and the source for random reconnection instant [V].

In the both analyzed cases it was considered that residual voltage rests at its maximum value on the positive demi-period of the supplying voltage.

In the same time, the equipment are subject of a thermal stress. The current on the uncontrolled line increases about 10 times, from 200A to 2100A (Fig.7).

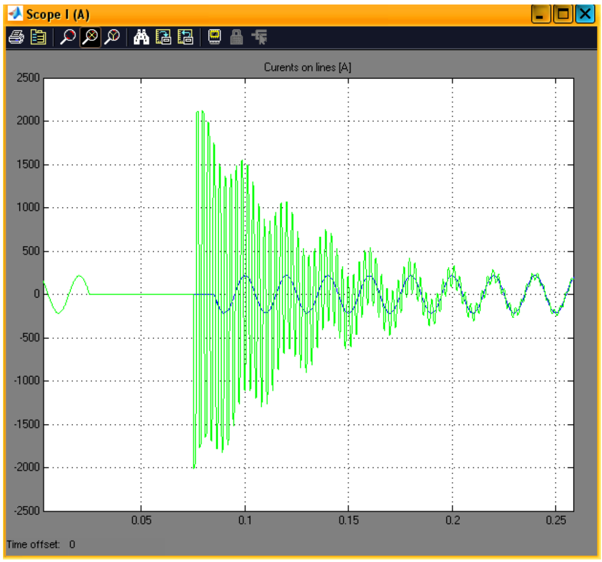

Fig. 7. Currents of the two lines.

For uncontrolled switching the situation is different. If the line voltage rests at its maximum negative value, the reconnection overvoltages are higher if the reconnection is executed in the instant when the difference between the line residual voltage and the source voltage is maxim (Fig.8).

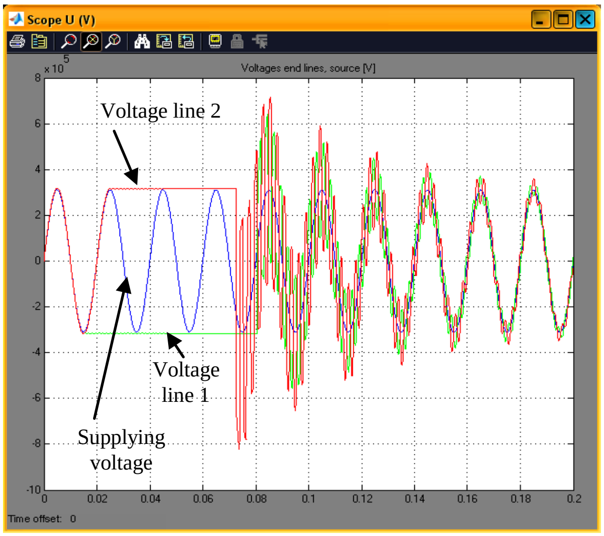

Fig. 8. Voltages at the end of the two lines and the source for maximum negative value of the line voltage [V].

In this case, even for the controlled commutated line, the reconnection over voltages are high: 700kV (Fig. 8) instead of 500kV, when the controlled disconnection is executed in the instant of the minimum difference between the residual voltage and the source voltage (Fig.4).

Even for uncontrolled disconnection, the maximum reconnection over voltages can be reduced down to the maximum source voltage if the controlled reconnection is considered (Fig.9).

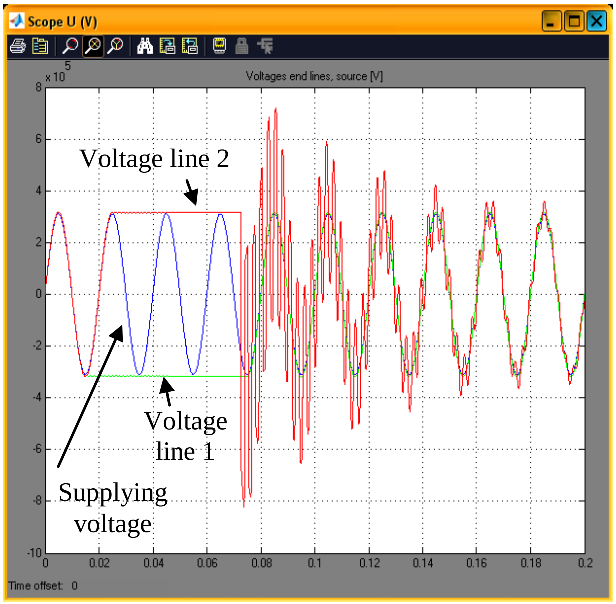

Fig. 9. Voltages at the end of the two lines and the source for controlled reconnection [V].

B. *The influence of the line length on the dielectric stress*

For a long line with the same parameters, the switching over voltages are analyzed if the length of the line is greater, l=300km respectively (Fig.10).

For relatively short lines (shorter than 400km) the residual voltage can be considered as being constant. For the longer lines, voltages oscillations occur on the disconnected line. They are caused by the voltage difference between the two ends in the very instant before the disconnection.

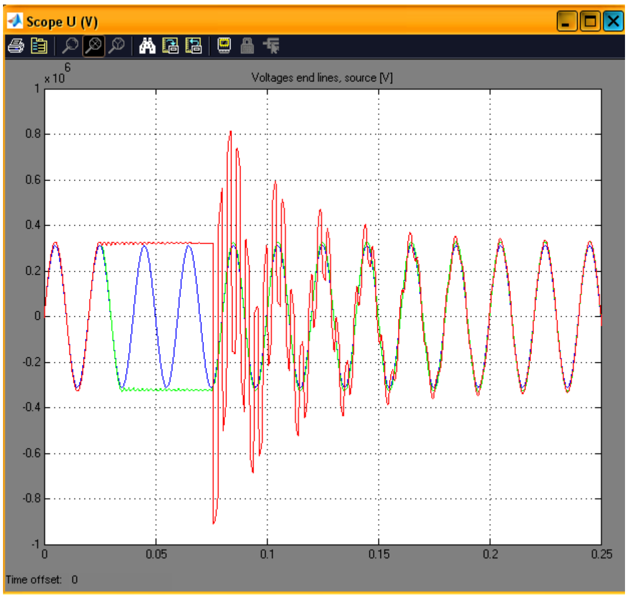

Fig. 10. Voltages at the end of the two lines and the source for other line length [V].

As presented in [10], one can notice that the peak overvoltage are higher when the line is longer, as can be seen in Fig. 10 vs. Fig. 8. The voltage slope arise to 9000V/μs for the uncontrolled line (line 2) vs. 6700V/μs for the 200km line (Fig. 5).

For lines longer than 400km, the over voltages are amplified by the voltage oscillations on the disconnected line[13]. They are caused by the voltage difference between the two ends in the very instant before the disconnection. For a 500km line, due to the voltage oscillations, the maximum overvoltage achieve 820kV (Fig.11) vs. 780kV (Fig.9).

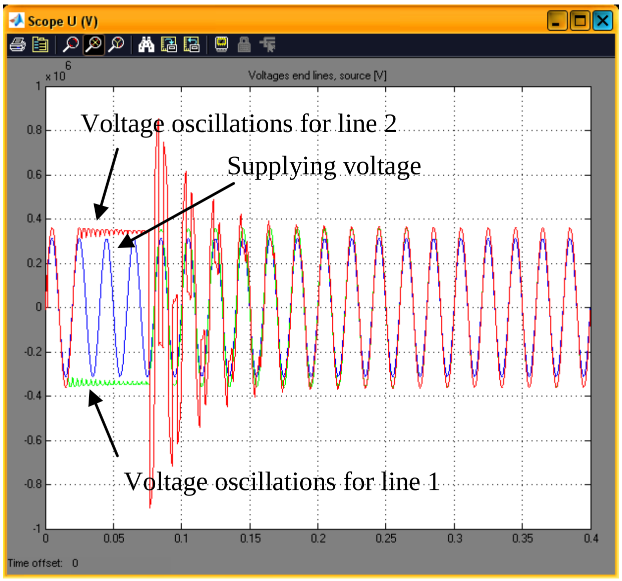

Fig. 11. Voltages at the end of the two lines and the source for line length 500km.

Consequently, the currents on the two long lines are higher, as can be seen in Fig. 12, face to Fig. 7.

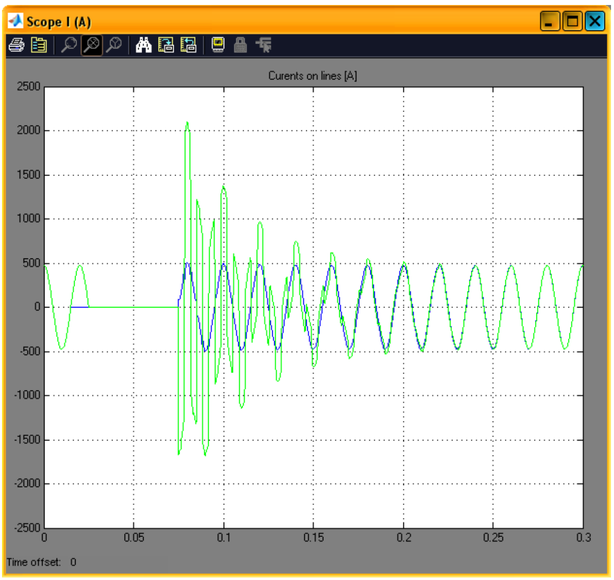

Fig. 12. Currents of the two lines for line length 500Km.

The stress of the electrical equipment increases when the lines length is greater due to the higher voltage slopes too, Fig. 13.

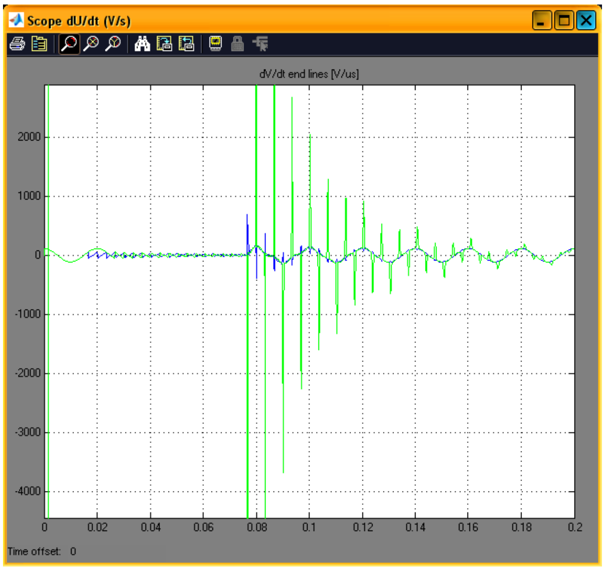

Fig. 13. Overvoltage's slope (dV/dt) at the long lines end for 500km length

VI. CONCLUSIONS

The paper has presented a monitoring system used for reducing of the electrical equipments stress in transport and distribution lines. The analysis algorithm is based on the analytical model method.

For the supplying interruption of the long lines, the situations when the commutation over voltages are the most dangerous were analyzed. The simulations highlighted that, after the occurrence of the fault, the control of the disconnection instant is the way for minimizing the over voltages.

Similarly, the controlled reconnection was studied. It also can be the solution for reduced commutation over voltages. In this way it results reduced stress of the electric equipment and longer live cycle.

Based on the analytical model, the influence of the line length on the dielectric stress for electric equipment in short or long transport and distribution lines (line length related to 400km) was also studied.

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Contribution of the authors:
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First coauthor – 20%
Second coauthor – 20%

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