On Some Mitigation Solutions for an Electromagnetic Interference Problem Analysis in Underground Cables

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*Abstract*—The paper approaches some electromagnetic interference issues that can occur between parallel underground electrical power line cables. An original method, which combines finite element electromagnetic field analysis, with Faraday’s law and electrical circuit theory, was used to evaluate induced currents and voltages in cable screening. Different steady state and power line fault operating conditions, combined with cable positioning and connection configurations had been investigated. Obtained computer simulation results were used in order to identify the proper mitigation techniques.

Keywords—electromagnetic interference; underground power cables; induced currents and voltages; mitigation techniques

# Introduction

Over the last decades, various studies have been made concerning the environmental effects of time varying electric and magnetic fields produced by A.C. currents flowing through high voltage or medium voltage electrical power lines [1-4]. Therefore, it is well known that due to inductive and capacitive couplings, dangerous electro-magnetic interferences could be induced in any metallic structure placed nearby overhead or underground power lines.

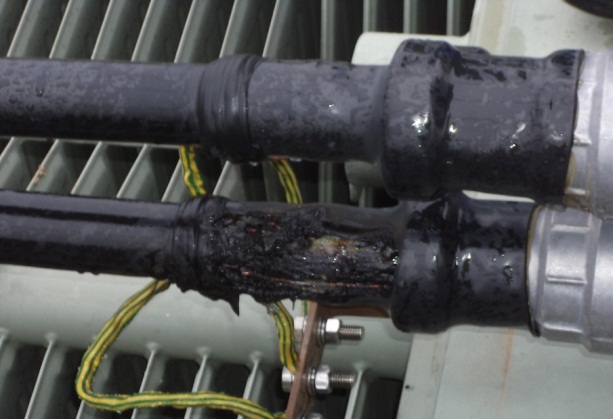
In case of underground electrical cables even cable screens, designed to attenuate the electric and magnetic field distributions in the surrounding zone, could be exposed to self-induced A.C. currents and voltages. These induced stray currents can lead to insulation overheating, jeopardizing the structural integrity of these cables [5, 6].

In order to attenuate power lines impact on the surrounding environment, numerous authors have already studied, by analytical or numerical methods, the electric and magnetic field distribution around three phase or single core underground electrical cables [7-10]. Also one can find various papers investigating the A.C. currents and voltages induced by power lines in nearby metallic structures (telecommunication cables, pipelines or fences), presenting different calculation methods [11-13] and analyzing the influence of various parameters and operating conditions [14-18].

The novelty in the current paper is that it approaches the self-induced A.C. interferences in single core medium voltage cable screens, in a practical case from Romania, which led to insulation degradation in a voltage rising power substation. In order to identify proper mitigation solutions, different connection configuration of cable screens to substation grounding grid are investigated in case of various steady state and power line fault operating conditions.

# Studied Electromagnetic Interference Problem

The case study relates to a new high voltage evacuation power substation, from Romania, designated to connect to the grid a group of wind turbines. In case of some single core power line cables used in three phase connection, placed between the medium voltage (33kV/50Hz) collecting bars and boost transformer (120MVA, 33/110kV) terminals, the degradation of outer insulating layer has been observed (fig. 1).



1. Insulating layer degradation on single core cables.

The connection path is formed by three ***N2XS2Y*** type single core medium voltage cables, per phase, which run parallel one to each other for approximately 50m. Each cable has a 500mm2 copper core, a 35mm2 copper screen separated with a 9mm thick XPLE foam polyethylene layer and a 3mm thick PE sheet. The underground cables are placed in three triangle form bundles grouped by voltage phase (RRR-SSS-TTT), using a 50cm separation distance between phase bundles, as in fig. 2 is shown:



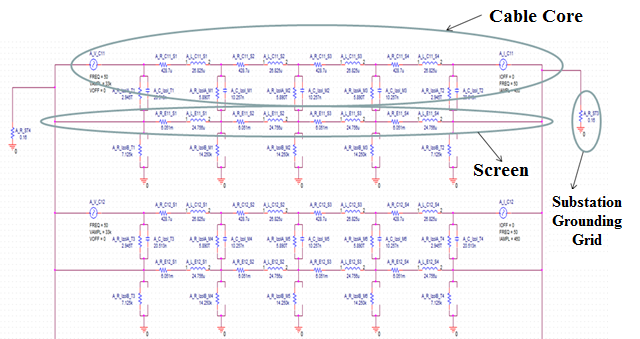
1. Parrallel single core cable bounding corridor.

According to substation working registry statistics the maximum steady state current load on each phase cable bundle could reach values of 2100A. And the most important fact, is that cable screens are connected at both ends to substation grounding grid. As a result the closed circuit loops which appear could facilitate currents flow through cable screens.

In order to determine the cause of cable PE sheet layer degradation, the electromagnetic coupling and induced AC current levels that could produce the overheating of cable screens are taken into consideration.

# Electromagnetic Coupling Evaluation

To evaluate induced AC currents and voltage levels in cable screens, a hybrid method combining field analysis with equivalent electrical circuit approach originally developed, by the authors, to investigate inductive and capacitive couplings between overhead high voltage power lines and nearby underground or over ground metallic pipelines [17, 20], has been adapted and applied for the current case study. In order to increase computation accuracy cable corridor has been divided in four equal sections, as in fig. 3:



1. Equivalent electrical circuit model.

## Equivalent circuit approach

For generating and solving the appropriate equivalent electrical circuit model (fig. 3), the following electrical parameters corresponding to a cable section have to be known:

#### **Longitudinal Impedance**:for each metallic object (copper core or cable screen), defined by conductor rezistanceand self inductanceon the specified k section:

 

where:

 

with: section k length;  and  conductor *i* resistivity and cross section according to section k.

The longitudinal impedances (self-inductances) of any two conductors *i* and *j* are magnetically coupled through a mutual inductance.

#### **Transversal Impedance**:,between cable copper core () and its screen () defined by separating XPLE insulation layer capacitance and rezistance for section k:

 

#### **Parallel Admitance**:,of the ith cable screen represented by an equivalent impedance in the specfic electrical circuit model:

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where the screen to earth impedance is defined by cable external PE sheet transversal capacitance and reyistivity coresponding to section *k*:

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## Electromagnetic field analysis

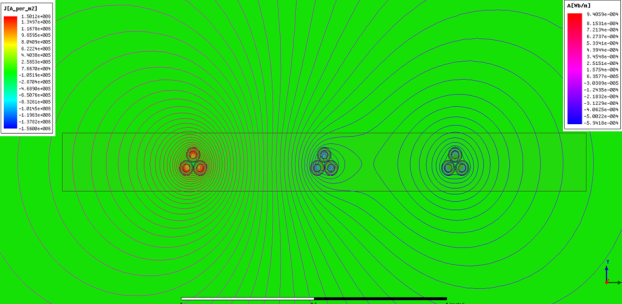
In order to calculate the self and mutual inductance matrix, describing the inductive couplig between any two metallic objects, an electramagnetic field analysis is performed.

Considering longitudinal symmetry conditions the presented case study can be reduced to a 2D field analysis problem in the *X-Y* plane acording to its cross-section. Thefore, the following equation system describing the linear 2D electromagnetic diffusion problem for the *z*-direction components of the magnetic vector potential  and the total current density  vector is obtained [18]:

 6

where *Jsz* is the source current density in the *z* direction and *Ii* is the imposed current on conductor *i* of *Si* cross section.

To solve this equation system a finite element calculation technique can be applied using dedicated software applications.



1. Electromagnetic field distribution around underground cables.

Imposing an arbitrary current *Ii* on one of the conductors *(condi)* and null currents on all the other metallic objects   
*(condj)* using Faraday’s law, the self and induced mutual inductances can be computed based on evaluated magnetic potential values on conductors cross-section:

 7

Performing a similar field analysis by imposing an arbitrary voltage *Vi* on one of the conductors and null potential on all the other metallic objects the conductor to conductor or conductor to earth capacitances can be determined by the produced electrical charge distribution conductor metals:

 8

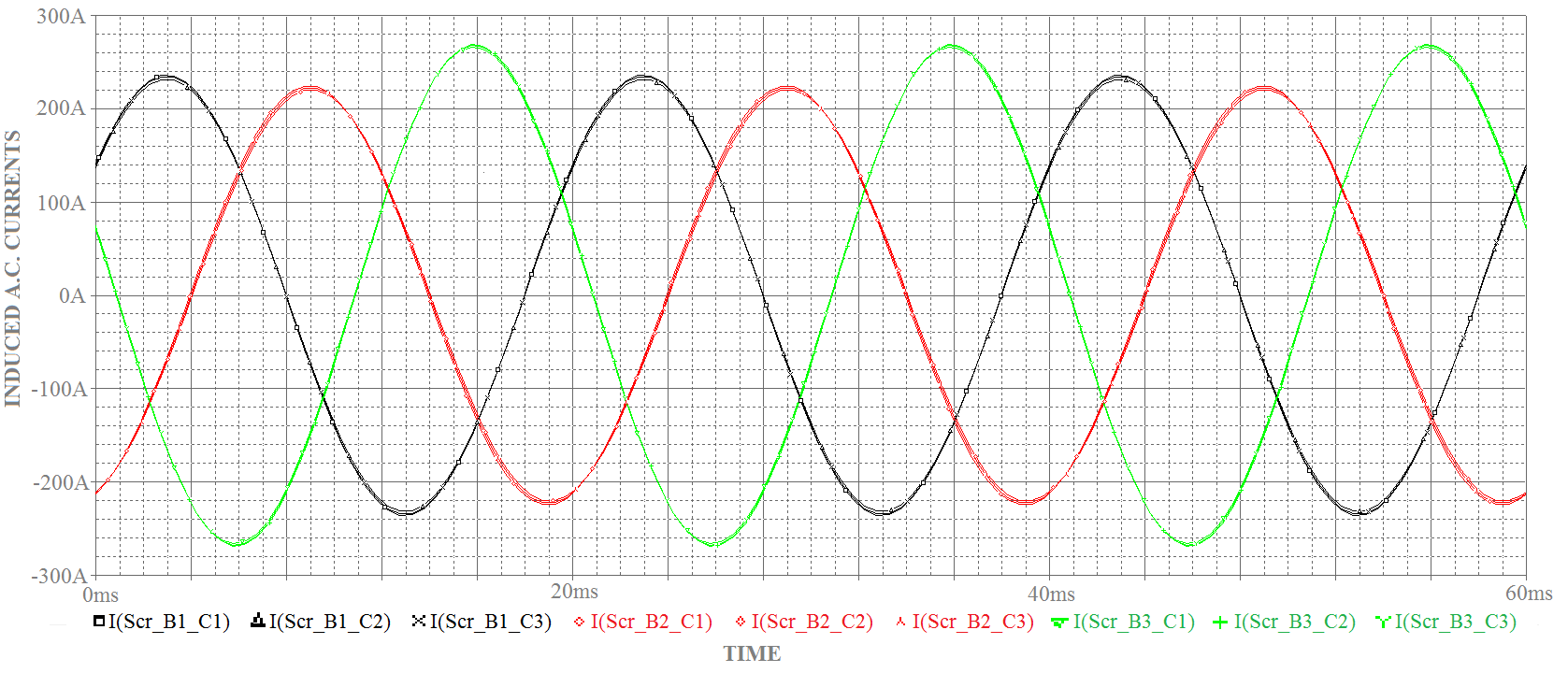
where *Ci,j* is the capacitance between cable core conductor *(condi)* and corresponding cable screen *(condj)*, *qj* is the induced electrical charge on cable screen by the imposed conductor voltage *Vi*.

# Induced Currents and Voltages

Using the presented equivalent electrical circuit approach the induced A.C. currents and voltages have been evaluated for each cable screen, due to inductive and capacitive coupling to cable conductor cores, by implementing the obtained electrical circuit model in OrCad PSpice.

## Stady State RRR-SSS-TTT cable bundle configuration

First the existing on site, power line configuration has been analyzed, for a steady state operating condition with an average 66% power load on substations boost transformer was considered, resulting in 1300A current flowing through phase bundles (433A per cable). Due to the short length of the bounding corridor, there are no variations of the induced current levels along cable screen length. Fig. 5 presents the obtained induced A.C. currents in cable screens at bounding corridor midpoint:



1. Induced currents in cable screens (RRR-SSS-TTT bundles).

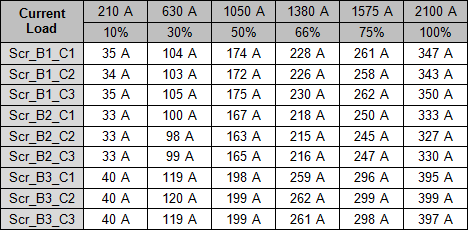
Analysis showed that due to cable positioning, in three triangle form bundles grouped by voltage phase (RRR-SSS-TTT), the generated electromagnetic field by cable conductor cores induces a very high current density in cable screens (*JScr=*7.14A·mm-2, almost double than the maximum allowed for copper conductors *JCu=*4A·mm-2), which explains the overheating and PE insulation sheet degradation at connection points:

 8

where: *JScr* is the produced current density in cable screen, *IInd* is the induced AC currents due to inductive and capacitive couplings and *SScr* is cable screen cross-section.

In order to perform a more detailed investigation the induced AC currents and voltages in cable screen have been computed for different power loads levels on substation boost transformer according to wind park energy production statistics:

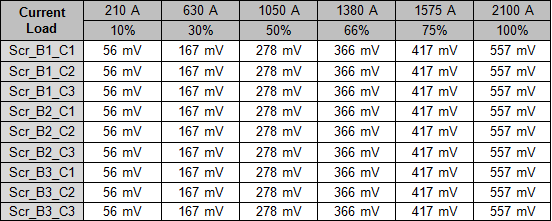
1. Induced A.C. Current Levels in Cable Screens



From the computed results (table I) it can be observed that induced A.C. current levels in cable screens increase with transformer load (current load on conductor core). Lower values are obtained for the middle bundle cables (B2) as an effect that the electromagnetic fields generated by the two side bundle cables (B1 and B3) are somehow compensating each other.

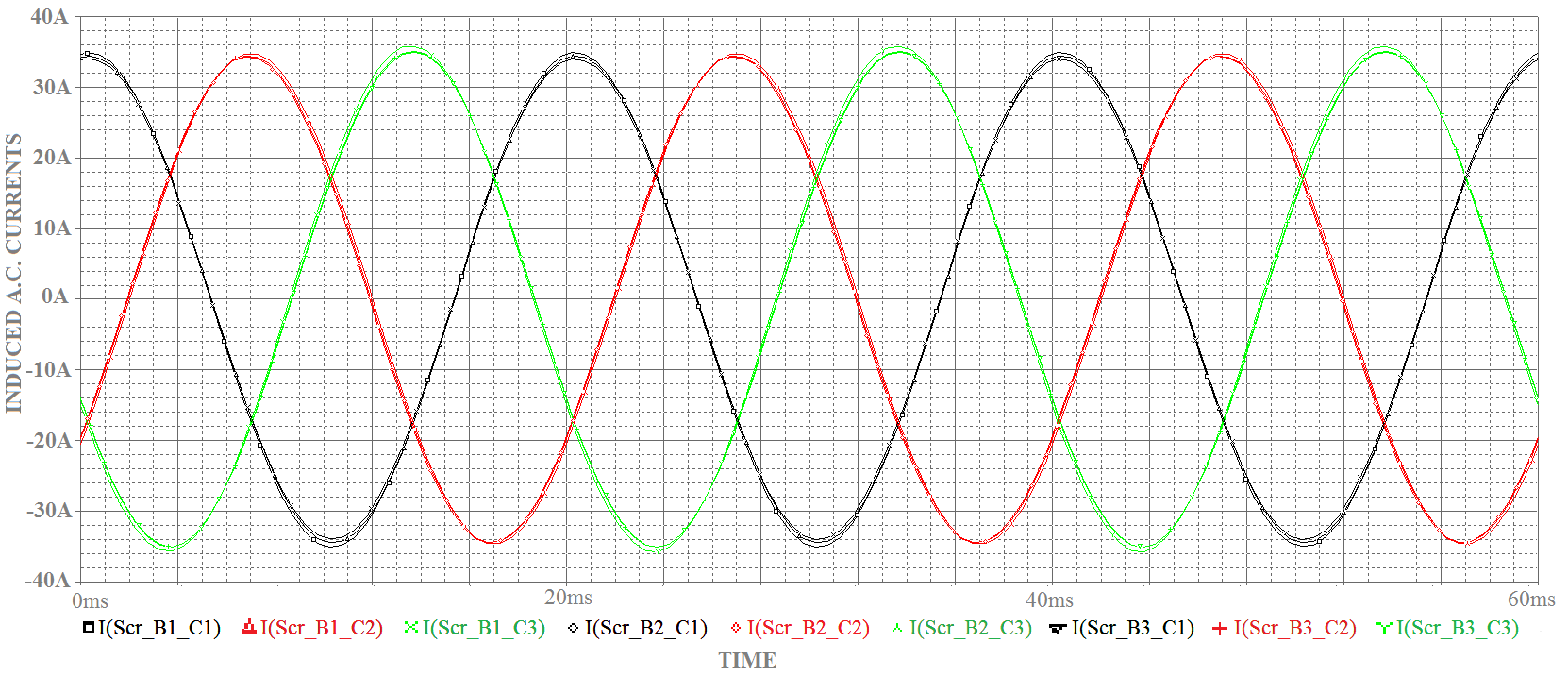
On the other hand, cable screens being connected at both ends to substation grounding grid, its potential rise compared to ground is less than 1V for the entire bounding corridor.

1. Induced A.C. Voltage Levels in Cable Screens



## Stady State RST-RST-RST cable bundle configuration

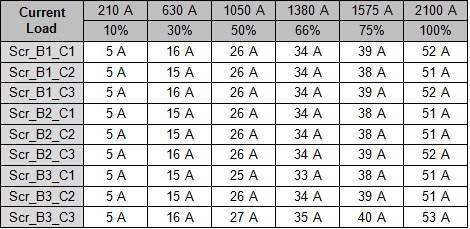
Previous electric and magnetic field distribution studies [8,10] showed that an RST phase conductor positioning inside cable bundles would reduce considerably the electromagnetic field distribution surrounding underground electrical cables. Therefore, in the following influence, of such a phase conductor positioning, on induced A.C. interferences in cable screens is investigated.



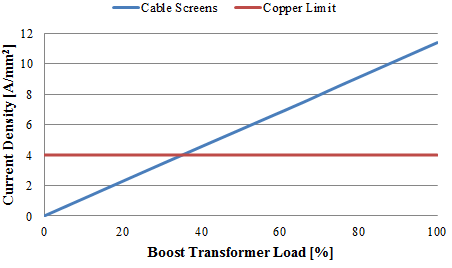
1. Induced currents in cable screens (RST-RST-RST bundles).

Fig. 6 presents the computed time varying induced currents in cable screens at bounding corridor midpoint, when a 66% boost transformer power load was considered. It can be observed that in this case the induced currents level decreases to 15% of the values obtained for the RRR-SSS-TTT cable positioning.

1. Induced A.C. Current Levels in Cable Screens



A more detailed analysis is showed in table III according to steady state current load on phase conductors. It was concluded that even for a 100% power load the induced current density would be less than 2A/mm2, eliminating the cable overheating phenomenon. However, due to economic reasons this phase conductor repositioning cannot be implemented on site.



1. Induced currents density in cable screens (RRR-SSS-TTT bundles).

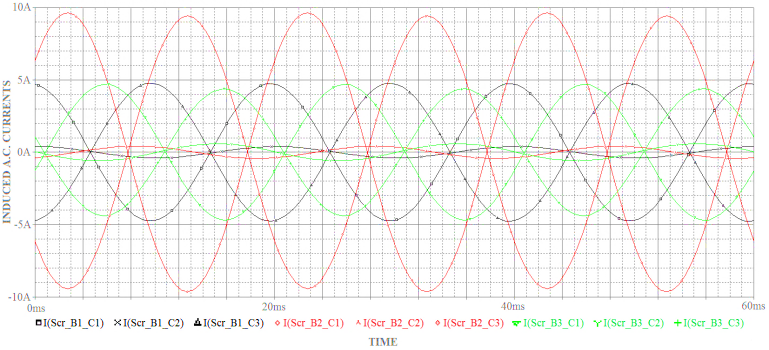
Analyzing cable screen current density variation (Fig. 7) for the existing on site cable positioning, it was identified that the maximum allowed current density in copper conductors is already exceeded from a 35% transformer power load. Therefore, to safely operate the existing underground cables configuration, an economical and electromagnetically compatible mitigation solution has to be determined.

# Mittigation Measures

In order to determine the proper mitigation solution that would limit the induced current flow through cable screens, for the existing on site cable layout, different scenarios were simulated by breaking up the circuit loop formed when the two ends of the cable screens were connected to substation grounding grid.

## Partial one side cable screens unboundling

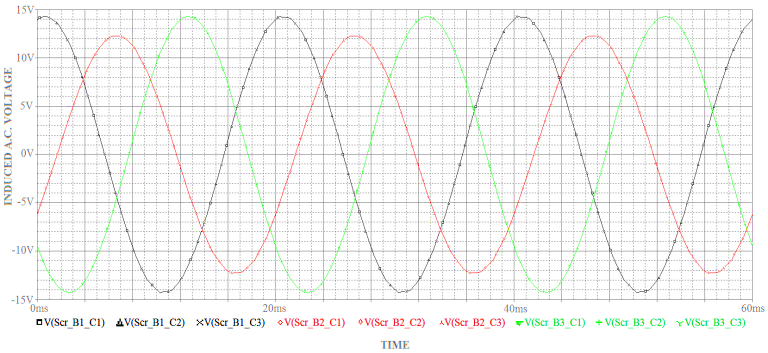
The first investigated cable layout configuration is the one when cable screens are unbounded at one end from substation grounding grid, but they remain bounded per phase bundles between each other on that end. On the other end cable screen connections to grounding grid are kept unchanged.



1. Induced currents in case of an one side cable screen unbounding.

Fig. 8 presents the evaluated maximum induced A.C. currents that can appear during steady state operating conditions in cable screens at bounding corridor midpoint. However the induced currents level decreases considerably, due the fact that cable screens are connected between each other, per phase bundles, at the unbounded end, a loop current appears inside each phase bundle. Also it can be observed that in this case the highest induced current level is obtained for the middle bundle cable screens.

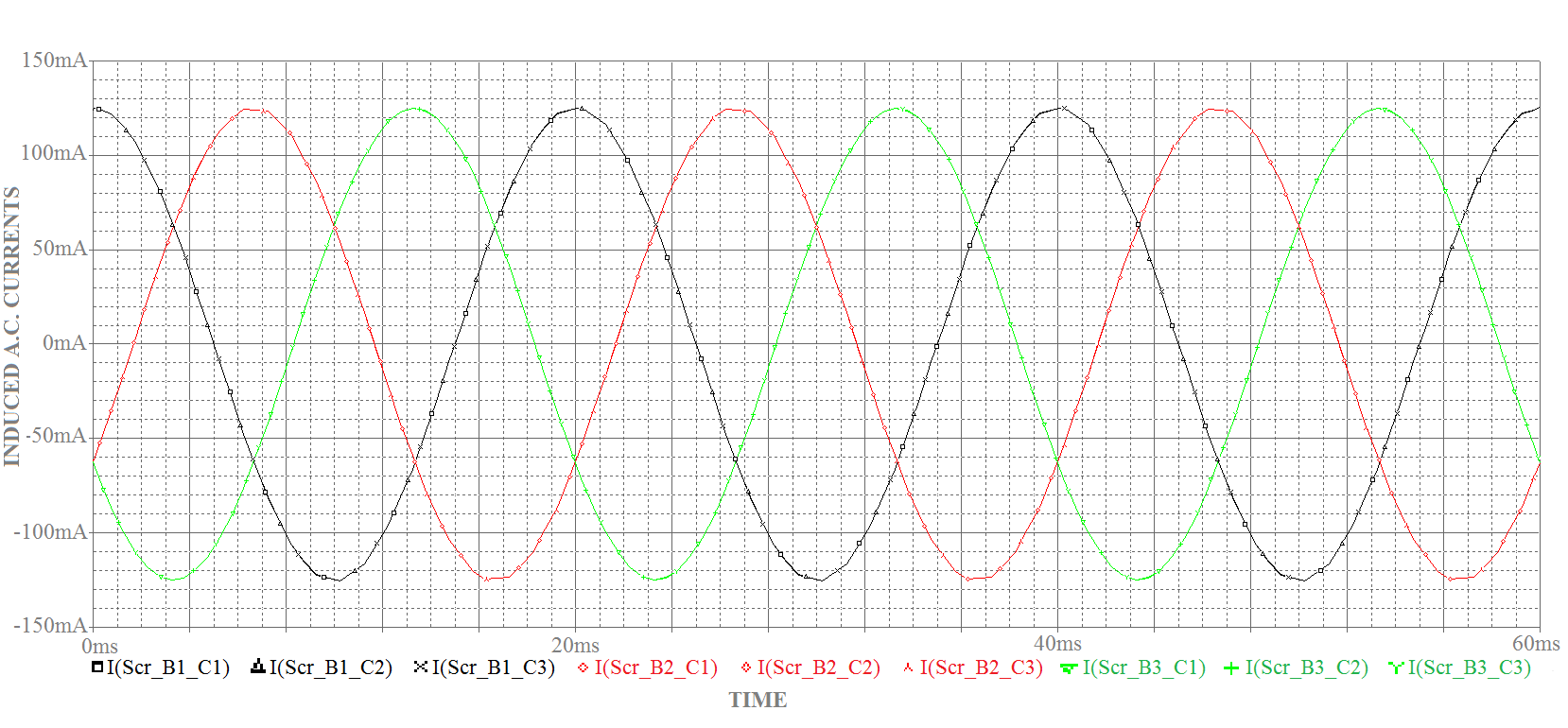
On the other hand, due to the unbundling from the substation grounding grid, a potential rise appears in cable screens at the unbounded end (see fig. 9).



1. Induced voltages in case of an one side cable screen unbounding.

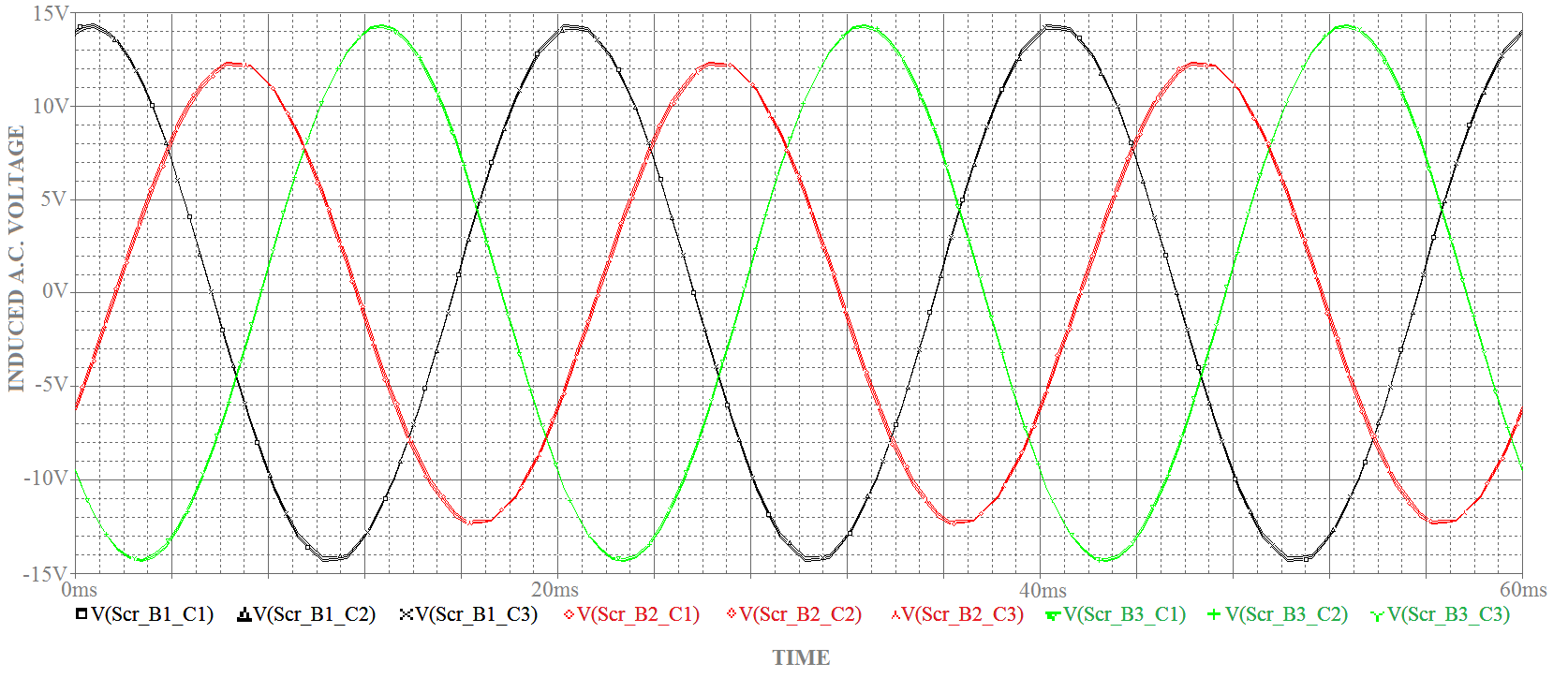
## Total One side cable screens unbounding

For the second investigated cable layout configuration, it was considered that cable screens are totally unbounded at one of the ends from substation grounding grid end, with no interconnection between cable screens at that end. Obtained simulation results for induced A.C. currents in case of a steady state operating condition with a 100% power load on the evacuation transformer, are presented in fig. 10:



1. Induced currents in case of a total one side cable screen unbounding.

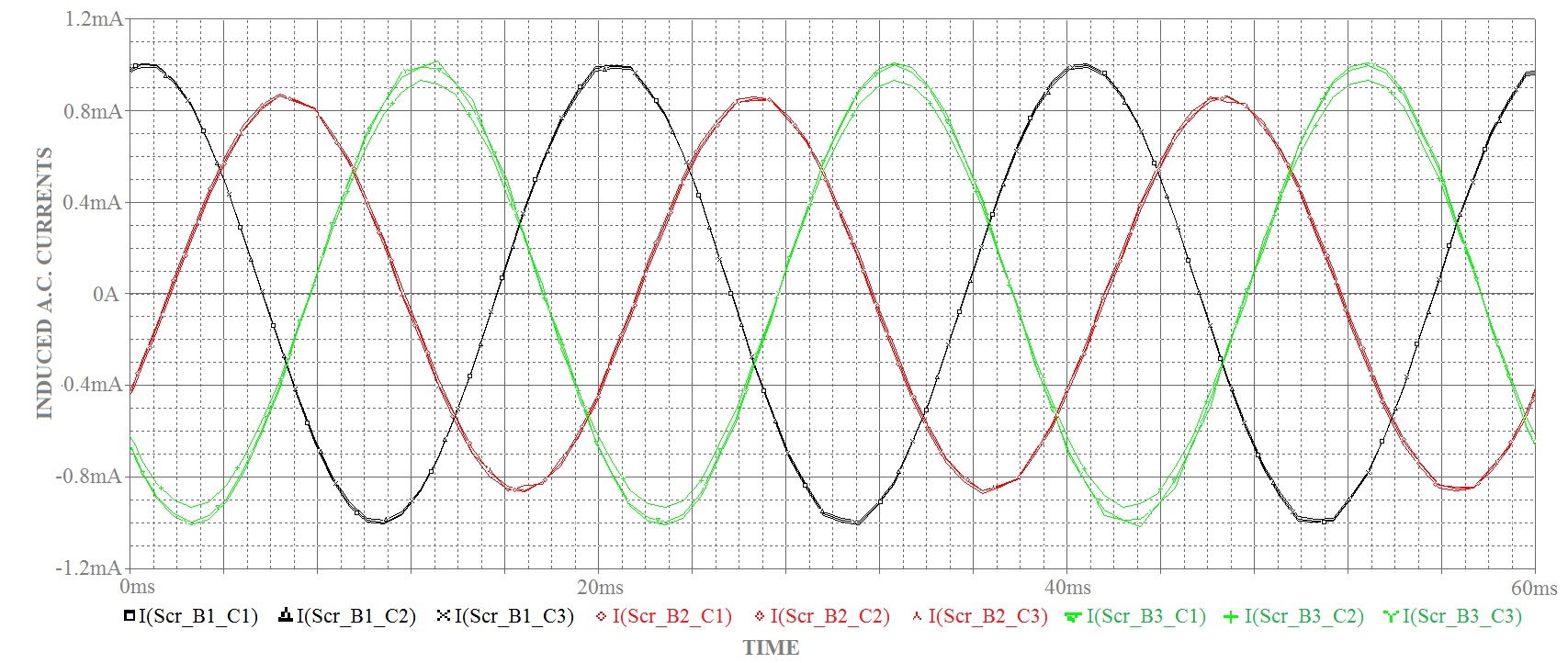
It can be observed that by totally unbundling at one end, the conducting loop formed by cable screens are broken, therefore the induced A.C. currents give rise to a path through cable insulation sheets, resulting in induced current levels lower than 1A. In the meantime the potential rise that appears at the unbounded end of cables screens reaches the same levels as in the previously investigated configuration, see fig. 11:



1. Induced voltages in case of a total one side cable screen unbounding.

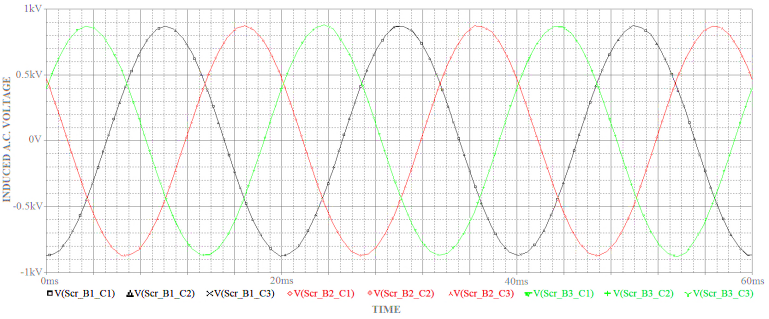
## Both side cable screens unbounding

Finally, it was simulated the case when both ends of cable screens would be unbounded from substation grounding grid. As a result, in this case cable screens lose their ability to reduce the electric field distribution in the surrounding media. However, there will be no more current flows through cable insulation at bounding corridor both ends. Therefore, the induced A.C. currents in cable screens would be almost null, see fig. 12:



1. Induced currents in case of a two side cable screen unbounding.

On the other hand cables screen being insulated from earth, cable insulating layers work as two series capacitors (cable core to screen, respectively cable core to earth) producing an electrical charge distribution that results in a significant potential rise of cable screens according to the ground potential. This fact can be a serious electrocution danger to operating personal, as in Fig. 13 is shown:



1. Induced voltages in case of a two side cable screen unbounding.

# Faulted Operating Conditions Testing

Analyzing the simulation data obtained for the investigated three mitigation measures it was concluded that the two one side unbundling configurations can be assumed to present a technically and economical reliable solution to limit induced current flows through cable screens, and so to prevent future cable insulation degradation. However, to provide proper protection to operating personal the induced A.C. voltages, that are expected to appear during transformer short-circuit faults, have to be analyzed.

Using fault current values provided by substation operating personal the induced A.C. voltage at the unbounded cable screen ends have been computed for both partial and total one side unbundling scenarios. There have been considered four different transformer short-circuit faults: single phases (phase R) to ground short-circuit, a two phase short-circuit (between phases S and T), a two phase with ground short-circuit and respectively a three phase short-circuit. Similar results being obtained for both investigated bounding configurations:

1. Potential Rise for Fault Current Peak Value

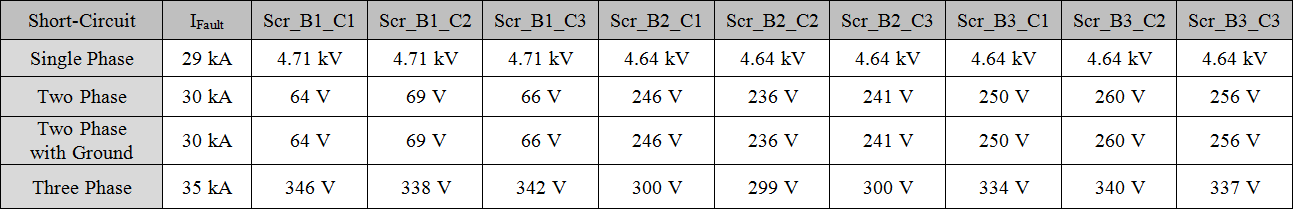
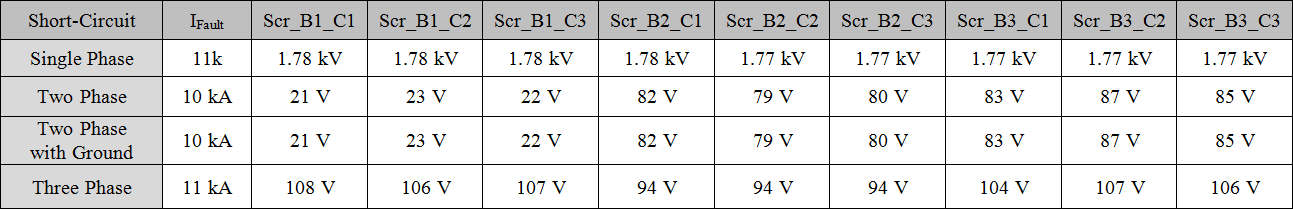


Table IV and V presents cable screens unbounded end potential rise for the peak and respectively the leveled values of the examined short-circuit fault current. It can be observed that during single phase faults cable screen potential rise could reach up to 4kV. Therefore, to provide safety to the operating personal, voltage surges should be placed at the unbounded ends, that will connect cable screen to substation grounding grid. However, this will produce a temporary increase of the induced A.C. current flows through cable screen that will last until the substation protection system disconnects the faulted power line.

1. Potential Rise for Fault Current Leveled Value



# Conclusions

The paper investigates a new Romanian high voltage evacuation power substation, designated to connect to the grid a group of wind turbines, where due to power cable screen overheating, insulation sheet degradation has been detected. In order to determine the cause of the overheating phenomenon the electromagnetic interferences that could appear between cable conducting cores and their screens were analyzed.

To evaluate induced A.C. current and voltage levels in cable screen a hybrid method has been adopted and applied, combining field analysis with an equivalent electrical circuit approach, originally developed by the authors to compute induced interferences in metallic pipelines placed near overhead power lines.

For the scope of identifying the proper mitigation solution, different cable layout configuration, steady state and power line fault operating conditions were simulated and analyzed.

Based on the obtained results it was concluded that for the presented interference problem the practical solution that has to be applied on site, is the partial on side cable screens unbundling from substation grounding grid, with voltage surges placed on each phase bundle cable screen interconnection.

##### Acknowledgment

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