Short-circuits simulation at 25 kV, 50 Hz contact line system

R. Doleček [1], O. Černý[1]

[1] Department of electrical and electronic engineering and signaling in transport
University of Pardubice
Jan Perner Transport Faculty, KEEZ, Studentská 95, 532 10 Pardubice
The Czech Republic
Phone: +420 466 036 427, fax: +420 466 036 497, e-mail: **radovan.dolecek@upce.cz**, **ondrej.cerny@upce.cz**

Abstract. The paper deals with the problem of behaviour of 25 kV, 50 Hz supply system at Czech Railways. Traction supply system is represented by contractor supply line 110 kV, supply substation and contact line. The main problem is short-circuits at contact lines. These effects can arise during failure states of traction circuit. It is necessary to know exact behaviour of traction circuit for adjusting of operation protections.

Key words

Filter-Compensation Equipment, Supply Substation, Harmonics, Transient Effect, Short-Circuit, Contact Line.

1. Introduction

At present, Electromagnetic compatibility is discussed a lot. Therefore Czech Railways need to use Filter-Compensation Equipment (FCE) into traction substations. This equipment is utilized for power factor corrections. It has been also used to reduce current harmonics caused by electric locomotives with diode converters.

The problem is short-circuits at contact lines. It was necessary to explain these effects which can occur during failure states of traction supply system. Firstly, detail analysis of traction circuit is carried out. Then design of these effects which are conducted by computer simulation. The computer simulation is designed for each individual traction circuit. These tractional models present input data for simulations by program (PSpice). The critical states are deduced from current and voltage knowledge which present output of simulation program. The electric values are gained by analysis of these states.

2. FCE characteristics at Czech Railways

Filter-Compensation Equipments are designed in this way:
FCE, which is shown (Fig. 1), contains two parallel series LC branches of the 3rd and the 5th harmonic with parallel connecting a decompensation branch. The tuning of the LC branches is not made for number of harmonic exactly but it is made for low-order of value as n_3 = 2.90–2.95 and n_5 = 4.98–5.00. The requirement on sufficient total input impedance (i.e. Z_{input}= 500 – 900 Ω) for operating frequency $f_{ripple\ control}$ are realized by the suitable option of C_3 and C_5 values in branches. This is to certify they depend on each other. The 5th harmonic LC branch is connected by disconnecting switch, thereby is carried out filtration requirement. It has to start at the lowest number of the harmonic. The structure of FCE provides the addition of the 7th harmonic LC branch. The decompensation branch includes reducing transformer, thyristor phase controller and decompensation chokes. The decompensation is made by decompensation choke which is controlled. Thus control is realized with inductive power factor DPF = 0.98 of input power. Creation of additional harmonics (i.e. primarily the 3rd harmonics) into voltage of 27 kV busbar is raised by partial controlling of controller of the decompensation branch. The sum of two harmonics (i.e. the 3rd harmonic of controller and the 3rd harmonic of network) could overload the 3rd harmonic LC branch.

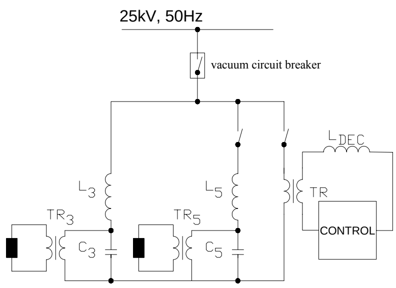

Fig. 1. FCE connection diagram.

3. Configuration 25 kV, 50 Hz traction supply system

Essential configuration 25 kV, 50 Hz traction supply system at Czech Railways is made by [1]:

- Contractor supply line 110 kV
- Supply substation
- Contact line

4. Transient effects solution

Transient effects are analyzed at linear systems. So we usually solve equations system which describes following effects. It was necessary to avoid building of a physical model. This model would be high financial-intensive or loss of process monitoring ability and behaviour of circuit at operation conditions. Thus simulation program (i.e. PSpice) was chosen. PSpice utilizes substitution diagrams of simple connections of traction circuit as input data. These diagrams are made from substitution models of simple elements of traction circuit.

Now, it is very important to say about the main disadvantages of computer simulation. The program does not work with real elements but it works with models. So results can be as exact as elements models and describe only effects which present using models. A creation of quality models, which represent real devices well, is the most important and the most complicated problem of simulations of electronical circuits.

Therefore models were made for all parts of traction supply system in this way.

A. Substitution of Homogenous Line by two-port network

The supply line and the contact line have the same character of homogenous line with distributed electrical parameters. They can be considered as a long electric line, see [2]. This long line can be substituted by two-port network as π - element or T - element with the distributed electrical parameters or the electrical long line with parameters which are: series specific resistance R_5, series specific inductivity L_5, parallel specific capacity C_5, parallel specific leakage G_5. Validity of substitute is cited in [3]. Thereinafter hold generally two general equations (1) and (2) for the homogenous line with the distributed electrical parameters, see (Fig. 2).

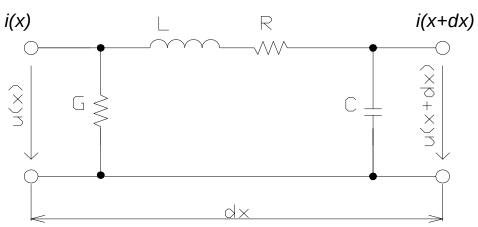

Fig. 2. Section of homogenous line.

$$-\frac{dU}{dx} = I\left(R + j\omega L\right) \quad (1)$$

$$-\frac{dI}{dx} = U\left(G + j\omega C\right) \quad (2)$$

B. Substitution of Supply Line

In this case, it is preferable to respect the supply line 110 kV as a line with inductivity L_5 and capacity C_5 (i.e. ignored line leakage G_5 and line resistance R_5). The fact, which makes this simplification, is mentioned in [2]. The specific electrical parameters of a supply line depend on construction and used materials of line. It can be also possible to ignore capacity C_5 because error would not assume great values. The substitution of the supply line is converted on one series inductivity with value L_{110} = 2 mH.

C. Substitution of Contact Line

The contact line is the electrical homogenous line with the distributed electrical parameters and it can be presented as a long electrical line, see [4]. This precondition can be taken because sections of track contact line are longer in comparison with sections of station contact line. The model of homogenous line has also four parameters, see (Fig. 3). There are: series specific resistance R_{CL}, series specific inductivity L_{CL}, parallel specific capacity C_{CL}, parallel specific leakage G_{CL}.

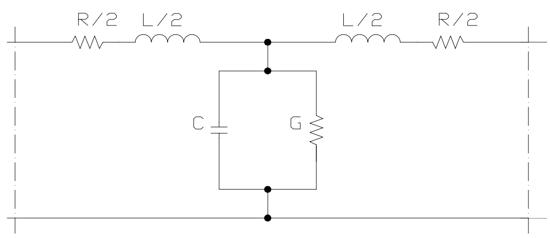

Fig. 3. Substitution diagram of contact line.

Specific leakage G_{CL} of contact line and specific leakage G_{CL} of others lines, which are connected with the contact line, are left out by calculations because it has very good isolation in the case of the contact line. This possibility is given by properties of the using line insulators and elimination of possibility of their surface pollution by ending of stream traction. So specific leakage runs into very high values and enables simplification; see [5] and [6].

Specific resistance R_{CL} and specific inductivity L_{CL}, which are frequency dependent, enter into calculation. Current, which pass through conductor, is pushed out on conductor surface (i.e. skin-effect) by increasing frequency. Then useful section of conduction (i.e. effective section of conduction) is decreased and specific resistance R_{CL} is increased. Current is decreased by skin-effect, so loop area decreases, too. Specific inductivity L_{CL} decreases until definite frequency where it remains constantly. Specific capacity C_{CL}, which is made by capacity of all conductors have traction voltage, is measured up by returned line which is represented earth. Its numerical values will depend on number of conductors, their height, their external diameter and also a configuration of neighboring electrified railway track (tunnel, railway cutting, railway embankment, station etc.).

The values for substitution diagram of losses homogenous line with the distributed electrical parameters of the contact line (i.e. 100Cu + 50Bz) are:

- Series specific resistance R_{CL} = 0.4 Ω.km^{-1}
- Series specific inductivity L_{CL} = 1.0 mH.km^{-1}
- Parallel specific capacity C_{CL} = 15 nF.km^{-1} (without intensive line)
- Parallel specific leakage G_{CL} = 0 S.km^{-1}

D. Substitution of Transformer 110 kV / 27 kV

The traction transformer 110/27 kV can be presented only by one series inductivity L_{TT} in energetic harmonic area. Inductivity L_{TT} is given short-circuit voltage of the traction transformer and series resistance R_{TT} which represents active losses. The values of alternate series inductivity depend on a used tap of the transformer because the transformer ratio can be a little bit different for each transformer. These transformers have wide regulation range of output voltage (i.e.2 x 8 taps) which can be changed under power. Current harmonics pass through the traction transformer and they are changed only by a used winding ratio. Thus we receive the values for the traction transformer (nominal power 10 MVA) and short-circuit active losses (53 kW):

- Series inductivity L_{TT} = 24 mH
- Substitute resistance R_{TT} = 0.39 Ω

E. Substitution of Filter-Compensation Equipment

Device of supply substation Modřice was chosen for FCE substitution diagram, see [7]:

<u>The 3rd harmonic LC branch</u>

- Total condenser capacity C_3 = 8.5 μF
- Resonance choke inductivity L_3 = 137 mH
- Choke resistance R_{L3} = 1.43 Ω
- Inherent resonance frequency f_3 = 147.5 Hz

<u>The 5th harmonic LC branch</u>

- Total condenser capacity C_5 = 2.4 μF
- Resonance choke inductivity L_5 = 169 mH
- Choke resistance R_{L5} = 1.77 Ω
- Inherent resonance frequency f_5 = 249.9 Hz

<u>Instrument voltage transformers</u>

- Substitution inductivity L_{TR} = 6079 H
- Substitution resistance R_{TR} = 9945 Ω

<u>Decompesation branch</u>

- Reducing transformer 27 kV/6 kV.
- Air-core choke, we receive decompensation branch total inductivity at site 27 kV L_{DEC} = 0.596 H and decompensation branch resistance $R_{L,DEC}$ = 6.24 Ω.
- Phase controller COMPACT, its control angle is calculated from values of instrument voltage transformer and instrument current transformer, so in order to values of power factor are DPF = 0.98. This value is measured in the connecting point of the supply substation with the contractor supply line 110 kV.

5. Short-circuits

A. Short-circuit at the end of the contact line which is represented as one section

The circuit diagram for the examinant effect is shown (Fig. 4). Short-circuits is made by traction voltage maximum.

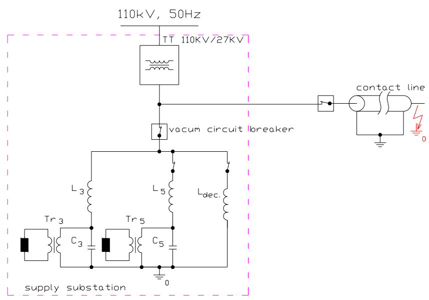

Fig. 4. Traction circuit diagram by short-circuit at the end of the contact line which is represented as one section.

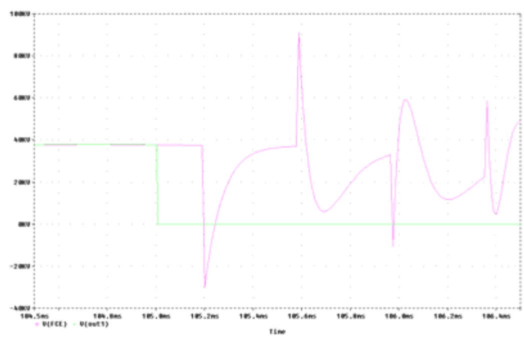

Fig. 5. Voltage waveform at supply substation (V (FCE)) after short-circuits at the end of the contact line.

Wave comes to the open end of the homogenous line it is reflected with the same polarity as original wave. Wave comes to short-circuit end of homogenous line is reflected with inversed polarity than original wave.

Delay Time of voltage surge pass through one direction of the selected section of the contact line is given by equation:

$$TD = l_{CL} \cdot \sqrt{L_{CL} . C_{CL}} = 193\ \mu s \qquad (3)$$

where l_{CL} is selected length of supply section (i.e. $l_{CL} = 50$ km), L_{CL} is series specific inductivity of contact line (i.e. L_{CL} = 1.0 mH.km^{-1}) and C_{CL} specific capacity of contact line (i.e. C_{CL} = 15 nF.km^{-1}).

B. Short-circuit at the end of the contact line which is represented as two symmetrical sections

The circuit diagram for examinant effect is shown (Fig. 6). Short-circuits is made by traction voltage maximum.

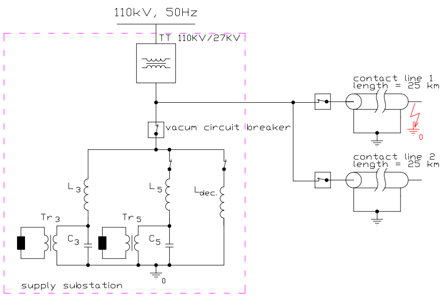

Fig. 6. Traction circuit diagram by short-circuit at the end of the contact line which is represented as two symmetrical sections (i.e. contact line 1 and contact line 2).

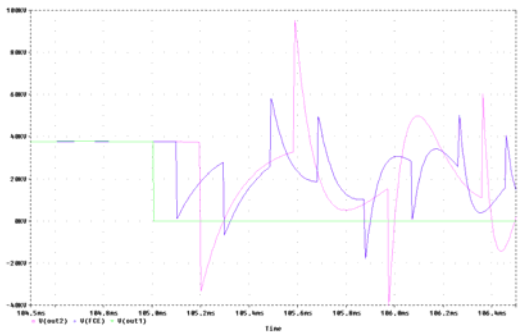

Fig. 7. Voltage waveform at supply substation (V (FCE)) and voltage waveform at the end of contact line 2 (V (out2)) after short-circuits at the end of contact line 1.

C. Short-circuit at contact line which is represented as two non-symmetrical sections

The circuit diagram for examinant effect is shown (Fig. 8). Short-circuits is made by traction voltage maximum.

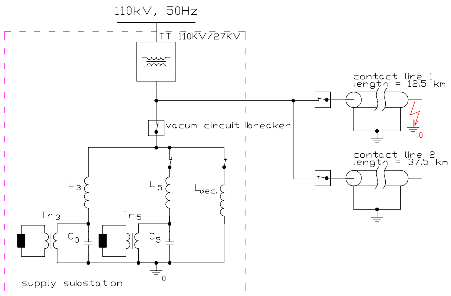

Fig. 8. Traction circuit diagram by short-circuit at the end of the contact line which is represented as two non-symmetrical sections (i.e. contact line 1 and contact line 2).

Fig. 9. Voltage waveform at supply substation (V (FCE)) and voltage waveform at the end of the contact line 2 (V (out2)) after short-circuits at the end of the contact line 1.

6. Simulation results

- The electrical values (i.e. output voltage of supply substation) depend on conditions of creation of short-circuit at contact line. Creation of short-circuit is always made by maximum of traction voltage. The presented cases of short-circuits is made without any traction consumption.
- The creation of short-circuit at the end of the contact line cause a voltage surge at output of supply substation. The peak value of the voltage surge can get triple of peak value of traction voltage (i.e. 116.7 kV) theoretically. This peak value is given by the reflection of the voltage surge at the short-circuited end of the contact line and the input impedance of the supply substation. The time delay of the creation of this peak value depends on the length of the contact line. After other reflections, the peak value of the voltage surge increase by resistance of contact line. The voltage surge has waveform of short voltage pulse which takes few microseconds.
- The reflection of the voltage surge at the impedance of the supply substation does not

depend on number of LC branches of FCE. Because the supply substation from viewpoint of the contact line consists from parallel inductivities which are: Substitution inductivity of traction transformer (L_{TT} = 24 mH), substitution inductivity the 3rd harmonic LC branch (L_3 = 137 mH) and substitution inductivity the 5th harmonic LC branch (L_5 = 169 mH). The values of L_3 and L_5 are higher than L_{TT}. The supply substation has an inductive character and represents an open line for voltage surge during few microseconds.

- The supply method of others contact line has the main effect to the peak value of the voltage surge. The transformer 110 kV/27 kV can supply one section of the contact line or two symmetrical section of the contact line or two non-symmetrical section of the contact line. Now, there are three supplying ways of the contact line.
  - For one section of the contact line: The peak value of the voltage surge can be at output of supply substation.
  - For two symmetrical section of the contact line or two non-symmetrical section of the contact line: The peak value of the voltage surge can be at the end of the contact line 2. Because the impedance of the supply substation is higher than the impedance of the contact line 2 for the short voltage surge takes few microseconds. It is declared by [8]. So reflection at impedance of the supply substation does not arise.

The results, which are cited above, are confirmed in (Fig. 10). This graph describes:

- V (FCE) - voltage waveforms at supply substation after short-circuits at the end of the contact line.
- V (out2_sym) - voltage waveform at the end of the contact line 2 after short-circuits at the end of the contact line 1.
- V (out2_nonsym) - voltage waveform at the end of the contact line 2 after short-circuits at the end of the contact line 1.

The passes through the contact line for time (i.e. 193μs).This voltage surge is reflected at the open end with the same polarity and gets double peak value. Restoration of traction voltage is given by transient effect after reflection of voltage surge. This transient effect depends on parameters of contact lime, parameters of contractor supply line 110 kV and traction transformer 110 kV/27 kV. The voltage surge, which comes at the short-circuit end of contact line, reflects at this end of contact line with inversed polarity. This reflected wave comes to the open end of contact line where it reflects with the same polarity again. In this time, this wave can get triple peak value of traction voltage. The peak is created after time 3x193μs.

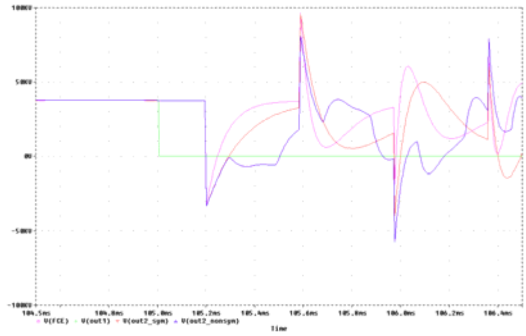

Fig. 10. Comparison of voltage waveforms

7. Conclusion

This paper is one part of large work. It was necessary to solve short-circuits without building of physical model. This model would be high financial-intensive. Therefore simulation program was chosen.
The design of protections is able to utilize for traction substation design with FCE. Simulation diagrams can be used as a main tool for particular project of traction substation with FCE of protection settings process.

References:

[1] V. VERZICH, Feeding systems of Railway interlock devices, TU ČD, Prague 2005, ISBN 80-85104-86-5 (in Czech).

[2] S. RAMO, R. J. WHINNERY and V. T. DUZER, Fields and Wales in communication electronics, Canada, 1993, ISBN 0-471-58551-3.

[3] H. BURRTSCHER, Laboratory model to examine extension and superposition of high frequency at railway network. Co-operator at Institution for AIE, ETH Zurich, ORE A 122 part 3.2 work program (in German).

[4] M. E. BAZELYAN, P. Yu. RAIZER, Spark discharge, New York CRC Press LLC, USA, 1998, ISBN 0-8493-2868-3.

[5] R. DOLEČEK, O. ČERNÝ, Analysis of 25 kV, 50 Hz traction supply system at Czech Railways. Journal WSEAS Transactions on power systems Issue 7, Volume 1, July 2006, pp. 1259-1266 ISSN 1790-5060.

[6] R. DOLEČEK, K. DVOŘÁK, Critical states analysis at 25 kV, 50 Hz contact line at Czech Railways, Proceedings of the 4th ISC „Challenges in Transport and Communication“ Pardubice, 2006, pp . 1319-1324, ISBN 80-7194-880-2.

[7] K. HLAVA, Analysis of conditions of FCE for supply substation Czech Railways Modřice, Prague, Report No.11/ 2005 (in Czech).

[8] M. NAHVI, J. EDMINISFER, Electric circuits, McGraw-Hill print, USA, 2003, ISBN 0-07-139309-2.