METHOD OF SOLUTION TO SHORT-CIRCUIT AT TRACTION SYSTEM

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1. Introduction

Current situation of railway technics is very complicated and sophisticated both from viewpoint of railway infrastructure and from viewpoint of transport means. The particular parts of the traction feeding system are necessary to be analyzed from viewpoint of their behaviour and from viewpoint of influence to surrounding parts of the whole system for exact and rapid understanding of effects and states which occur in traction energy systems. The paper deals with analysis of short-circuit at AC 25 kV, 50 Hz traction supply systems with the support of computer simulation. It was necessary to explain these effects which can occur during failure states at this system. 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. Traction Supply System 25 kV, 50 Hz

AC 25 kV, 50 Hz system general configuration at Czech Railways (i.e. traction circuit), see Fig. 1, is:

- Feeding Line 110 kV
- Supply Substation with Filter Compensation Device
- Contact line
Electric locomotive

![Diagram of electric locomotive system](image)

**Fig. 1** AC 25 kV, 50 Hz system

2.1 Filter Compensation Device

At the present day, Electromagnetic Compatibility (EMC) is discussed a lot. Therefore Czech Railways need to use Filter Compensation Device (FCD) into traction substations. The FCD is utilized for power factor corrections and also to reduce current harmonics caused by electric locomotives with diode converters which dominate at Czech Railways. Electrical locomotive with diode rectifier is all odd current harmonics generator (i.e. 3rd, 5th, 7th, and so on), see **Fig. 2**. The current harmonics pass through contact line, traction transformer, feeding line 110 kV and then main system.

![Current harmonic spectrum of diode rectifier](image)

**Fig. 2** Current harmonic spectrum of diode rectifier

FCD conception was chosen from the economic and the technical reasons, see **Fig. 3**. It has two series LC filter branches (i.e. for the 3rd, the 5th harmonic) and also decompensation branch. The LC branches tuning is not adjusted to the number of the harmonic exactly but it is done for lower value as n₃ = 2.90 - 2.95 and n₅ = 4.98 - 5.00, see [1]. This adjustment of LC branches is necessary because of harmonics from feeding line 110 kV (i.e. distribution network). These ones could overload the LC branches and this fact was confirmed by measuring. The whole device has to have sufficient total input impedance ($Z_{input} = 500 - 900 \Omega$) for used control frequency ripple control (216.67 Hz). This condition is realized by a suitable option of $C₃$ and $C₅$ values in the LC branches. This is to certify LC branches depend on each other. The decompensation branch consists of: reducing transformer, thyristor phase controller and decompensation coil. The control is made to inductive power factor $\text{DPF} = 0.98$ at electrical power input.

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3. Solution to Short-circuit at Traction Circuits

For simulation by programme PSpice, it is necessary to create models of parts traction circuits which are made substitution schemas from. The models present input data for simulation program PSpice. Output data of simulation program represent voltage and current waveform including their values. Accuracy and believability of simulations depend on input parameters and models of examined parts of circuit.

3.1 Model of Feeding Line 110 kV

Feeding line 110 kV has the character of homogenous line with distributed electrical parameters. They can be considered as long electric line. This long line can be substituted two-port network as π-element or T-element with distributed electrical parameters or electrical long line with parameters: series resistance $R_L$, series inductivity $L_L$, parallel capacity $C_L$ and parallel leakage $G_L$. Substitute validity is cited in [2]. The electrical parameters of feeding line 110 kV depend on line construction and used materials. Substitute only by capacity $C_{110}$ and inductivity $L_{110}$ is useful for analysis the feeding line 110 kV. Capacity $C_{110}$ can be also ignored because of error would not assume great values, so line model is converted on one series inductivity (e.g. $L_{110} = 2 \text{ mH}$).

3.2 Model of Contact line

Contact line can be presented as long lossy electrical line with the four electrical parameters, see [3] and [4]. For analysis, it was chosen the worst parameters of contact line at the structure 100Cu + 50Bz with total length 50 km this way: $R_C = 0.4 \ \Omega \cdot \text{km}^{-1}$, $L_C = 1.0 \ \text{mH} \cdot \text{km}^{-1}$, $C_C = 15.0 \ \text{nF} \cdot \text{km}^{-1}$ (without intensive line) and $G_C = 0.1 \ \text{mS} \cdot \text{km}^{-1}$. These parameters represent the worst situation from the viewpoint of simulations.

3.3 Model of Supply Substation

Supply substation contains two main devices from the viewpoint of analysis: traction transformer and filter compensation device.
Traction transformer 110/27 kV can be presented only by one series inductivity in the field of energetic harmonic. The inductivity $L_{TT}$ is given by short-circuit voltage of traction transformer and series resistance $R_{TT}$ is given by active losses. The value of series inductivity depends on used tap of transformer because 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 traction transformer and they are changed only by used winding ratio. For example, the values for traction transformer with nominal power 10 MVA are: $L_{TT} = 24 \text{ mH.km}^{-1}$ and $R_{TT} = 0.39 \Omega$.

Filter Compensation Device (FDC) is individual for each supply substation. For example, it was chosen the device with these parameters for analysis:

- The 3rd harmonic LC branch with parameters: total capacity $C_3 = 8.5 \ \mu \text{F}$; choke inductivity $L_3 = 137 \ \text{mH}$; choke resistance $R_{L3} = 1.43 \ \Omega$
- The 5th harmonic LC branch with parameters: total capacity $C_5 = 2.4 \ \mu \text{F}$; choke inductivity $L_5 = 169 \ \text{mH}$; choke resistance $R_{L5} = 1.77 \ \Omega$
- Decompenstate branch with parameters: total inductivity $L_{DEC} = 0.596 \ \text{H}$; resistance $R_{L,DEC} = 6.24 \ \Omega$

### 3.4 Model of Electric Locomotive

Electric locomotive is one of the most complicated parts due to variable parameters, because the model parameters are changed during locomotive running, see [5] and [6]. This part of traction circuits is solved in the next paper which represents other part of research work. Thus, for this analysis, the attention focuses on traction circuit without these locomotives.

### 3.5 Contact Line as One Section

![Diagram](image)

**Fig. 4** Contact line is represented by one section
**Fig. 5** Voltage for one section of contact line

**Fig. 6** Current for one section of contact line
3.6. Contact Line as Sections with Railway Station

Fig. 7 Contact line is represented by sections with railway station

Fig. 8 Voltage for sections of contact line with railway station
4. Conclusion

For the mentioned analysis of short-circuits at contact line, we gain the results lead to the following findings:

- The electrical values (i.e. output voltage of supply substation) depend on origin conditions of short-circuit at contact line. The short-circuit origin is always made by maximum of traction voltage. The presented cases of short-circuits is made without any traction consumption.

- From viewpoint of overvoltage, the worst case is when contact line is represented by one section. In this case, voltage surge is reflected at supply substation. Theoretically, peak values of voltage at supply substation output can gain triple of peak value of traction voltage (i.e. 116 kV). This value is given by wave interference. Contact line as long lossy line is ended by inductivity represented by inductivity of traction transformer \( L_{TT} = 24 \text{ mH} \). Internal impedance of source (i.e. 38.9 kV) can be considered as zero impedance. This inductivity seems as infinite impedance during a few milliseconds. The reflection of voltage surge on impedance of supply substation does not depend on number of LC branches of FCD because supply substation from viewpoint of contact line consists of parallel inductivities which are: traction transformer inductivity \( L_{TT} = 24 \text{ mH} \), inductivity of the 3\(^{rd}\) harmonic LC branch \( L_3 = 137 \text{ mH} \) and inductivity of the 5\(^{th}\) harmonic LC.
branch \( (L_s = 169 \text{ mH}) \). The real peak of voltage at output of supply substation is about 80 kV due to line losses which are higher than at simulation model.

- The similar situation, it come at contact line is represented by sections with railway station. The voltage surge can gain triple of peak value of traction voltage theoretically as well. The problem occurs at separate voltage surges at station sections. Overvoltage does not depend on number of station tracks, but it depends on the station tracks length. For other details, see [7].

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References

3. BURTSCHER, H. 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.
Summary

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The paper represents one part of research work on the field of traction system. At the present days, the situation of railway techniques is very complicated and sophisticated both from viewpoint of railway infrastructure and from viewpoint of transport means. Moreover electromagnetic compatibility stands out in all possible technical areas it leads to research work focused on influence to surrounding parts. So, it is necessary to analyze the particular parts of the traction supply system from viewpoint of their behaviour and from viewpoint of influence to surrounding parts. The paper deals with metod of solution of short-circuit at AC 25 kV, 50 Hz traction supply systems by computer simulation. It was necessary to explain these effects which can occur during failure states. The whole analysis is done with traction circuit without electric locomotives. The critical states are deduced from current and voltage knowledge and following analysis of these states we gain the results lead to the findings mentioned in the conclusion of this paper. This work can be used as one part of background for research work on the field of traction system. Usage of the mentioned control method opens up the others possibility for research on this field of interest.

Zusammenfassung

SIMULATIONSMETHODE ZUR LÖSUNG DER KURZSCHLÜSSE IM FAHRSTROMSYSTEM

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