# ELECTRICAL ENERGY QUALITY STUDIES IN 3kV DC ELECTRIC TRACTION SYSTEMS FOR DIFFERENT SCHEMES OF CONNECTION TRACTION SUBSTATION TO POWER UTILITY SYSTEM

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**Summary** The paper presents aspects of DC electric traction systems influence on electric energetic system. Study is based on modeling and simulation of electrified railway line. After simulation, there was performed analysis of energy quality, which using results of simulation and supply system parameters.

## 1. INTRODUCTION

Electric energy quality in electric traction systems is nowadays a subject of deep and thorough, both theoretical and practical, studies and analysis. It is resulted from introduction of standards [3] and TSI directives towards electrified railway lines. It is specifically important during modernization or design of power supply system, it is necessary to analyze, if it complies with requirements referring to quality parameters of electric energy at point of common coupling (PCC). Those standardized parameters are as follow: current and voltage frequency; voltage level; current and voltage balance time course of current and voltage instantaneous values.

## 2. DC ELECTRIC TRACTION SYSTEMS INFLUENCE ON ELECTRIC ENERGETIC SYSTEM

Rectifier groups installed in traction substations make non-linear loads. Course of current they consumed is a non-sinusoidal form. Harmonics of such current $I_{hi}$ (i-order of harmonic) flow through system impedance elements [1,2,4,6,7]. As a result, they cause harmonic voltage drops $\Delta U_{hi}$ on the system elements $Z(h_i)$.: $\Delta U_{hi}(t_j) = I_{hi}(t_j)Z(h_i)$. Finally, it is calculated as Total Harmonic Distortion THD U. Voltage harmonics can influence considerably quality of electric energy supply. This phenomenon refers both to traction substation and other receivers supplied from the same energetic station AC busbars.

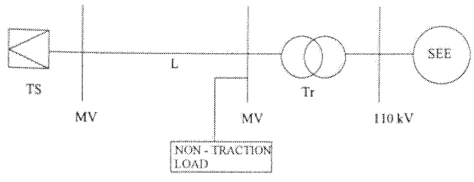


*Fig. 1. Typical scheme of traction substation supplying system in Poland (SEE – power system; MV – medium voltage (typically 15* kV) *busbars; L – supplying line; TS – traction substation)*

The second important aspect, which must be taken into consideration, are voltage fluctuations $\Delta U_{AC\%}(t_j)$ at AC busbars (flickers) caused by changing load $\Delta I_{AC}$ of electric traction substation, which may be described as voltage drops at power supply elements described by resistance R, reactance X and power coefficient cos φ divided by nominal voltage $U_{AC}$:

$$\Delta U_{AC\%}(t_j) = \sqrt{3}\Delta I_{AC}(t_j)[R\cos\varphi + X\sin\varphi] / U_{AC}100[\%]$$

It is resulted from power demand profile of electric locomotives – starting and coasting ride. Rapid traction load variations can be observed as significant voltage variations. The lower are power system short-circuit power, the higher are influence of electric traction.

Those two above mentioned phenomena can cause an improper operation of loads sensitive to energy quality: flickering, bad working of computers, measuring devices, remote control devices, telecommunication devices, electric machines etc. For these reasons, it is very important to estimate above phenomena, both for designing and existing electric traction systems.

## 3. SIMULATION MODEL

In order to assess the influence of the electrified railway line a model of electrified railway line oriented towards power balance has been used [ 5]. The input data are following:

- supply system parameters
- time – table of trains
- route characteristic (vertical gradient, curves, speed limits).
- rolling stock parameters.

Such model allows simulating the operation of electrified railway line in each second. The results of simulation are for example voltage and current courses.

After the simulation is finished, an analysis of voltage distortion and variations in selected nodes are performed:

- supply system values and load parameters,
- traction substation load course

THD U and variations of voltage are analyzed and compared to standards [3].

As an example of the application of the model, a part of being modernized railway line Warsaw – Lodz has been taken into account with two options of the traffic and power supply schemes:

- parameters of existing line (option 0),
- parameters of designed supply system for the forecasted traffic (option2).

Those aspects have to be taken in particular consideration because of traction substation supply system configuration. In both options, some traction substations are supplied from neighboring traction's AC busbars (B in Fig. 2).

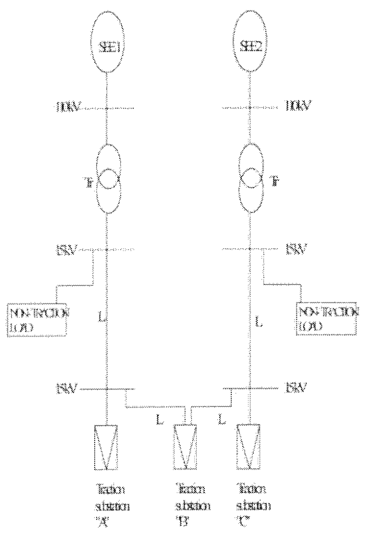

*Fig. 2. Traction substation supply system from AC busbars of a neighboring traction substation - (option 0).*

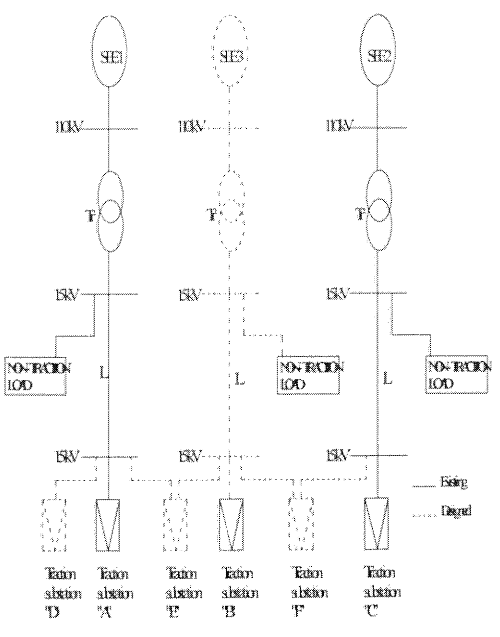

*Fig. 3. Traction substation supply system from AC busbars of a neighboring traction substation - (option 2) (D,E,F-new designed traction substations).*

Basic parameters of the power supply system are shown in tables 1a ÷ 1b

*Tab. 1a. Supply system parameters (option 0)*

| | **TS „A”** | **TS „B”** | **TS „C”** |
|---|---|---|---|
| R [1]) | 3 x PK17 | 3 x PK17 | 3 x PK17 |
| S [2]) | S | TS | S |
| Tr [3]) | 25 | 25 | 25 |
| $S_{sc}$ [4]) | 1459 | - | 1155 |

*Tab. 1b. Supply system parameters (option 2)*

| | **TS „A”** | **TS „B”** | **TS „C”** |
|---|---|---|---|
| R | 2 x PD16 | 2 x PD16 | 2 x PD16 |
| S | S | S | S |
| Tr | 25 | 25 | 25 |
| $S_{sc}$ | 1459 | 1500 | 1155 |

1) Type and number of rectifier groups [ - ]
2) Supply system (S – PCC; TS –AC busbars of a neighboring traction substation)
3) Rated power of transformer 110/15 kV [MVA]
4) Short – circuit power (PCC-HV busbars) [MVA]

   PK17-6-pulse; PD-16 –12-pulse

## 4. SIMULATION RESULTS

For option 0, simulation was performed assuming 3 – hour peak period of traffic on the line. There are shown in Figures 4 ÷7 results of simulations and analysis results obtained for the worst case - TS „C” AC busbars, which additionally supply TS „B” (results shown in Figures 8 ÷ 11).

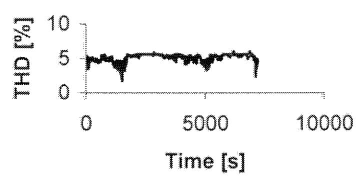


Fig. 4. Voltage Total Harmonic Distortion (THD) calculated at TS „C” AC busbars (option 0)

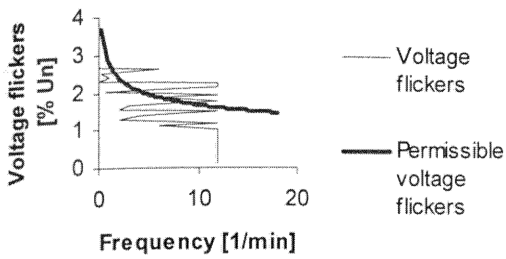


*Fig. 5. Voltage flickers calculated at TS „C" AC busbars and compared to assumed criteria (option 0).*

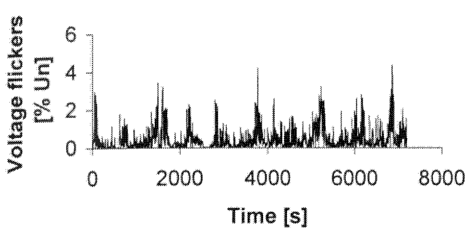


*Fig. 6. Voltage fluctuations (time course) calculated at TS „C" AC busbars (option 0).*

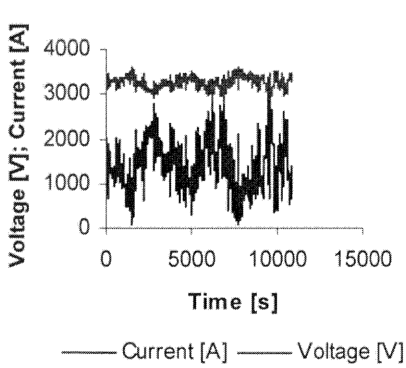


*Fig. 7. Load flow time course for TS „C" (option 0).*

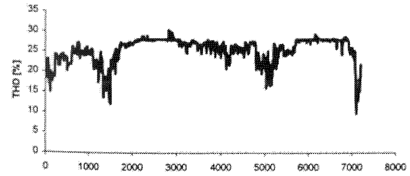

*Fig. 8. Voltage Total Harmonic Distortion (THD) calculated at TS „B" AC busbars.*

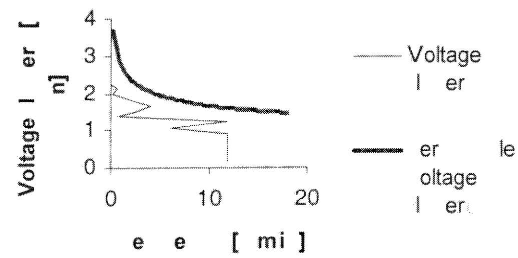


*Fig. 9. Voltage flickers calculated at TS „B" AC busbars and compared to criteria (option 0).*

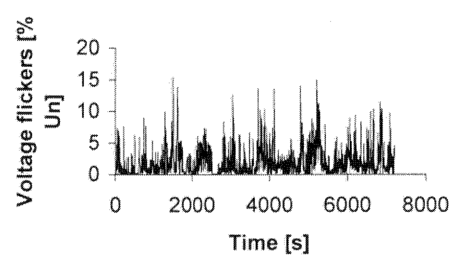


*Fig. 10. Voltage flickers (time course) calculated at TS „B" AC busbars (option 0).*

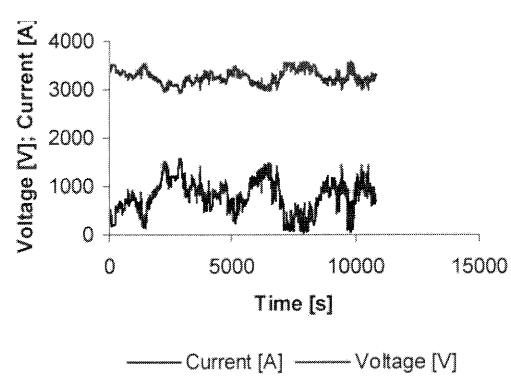


*Fig. 11. Load flow time course for TS „B" (option 0).*

There are presented in Figures 12 ÷ 19 results for TS "B" and TS "C" with twelve-pulse rectifiers (tables 1b ÷ 1b, Figure 3)

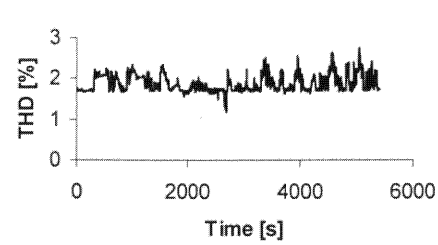


*Fig. 12. Voltage Total Harmonic Distortion (THD) calculated at TS „C" AC busbars (option 2).*

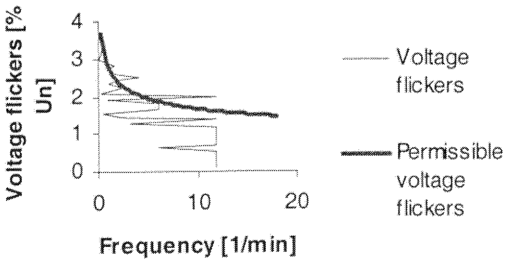


*Fig. 13. Voltage flickers calculated at TS „C" AC busbars and compared to criteria used (option 2).*

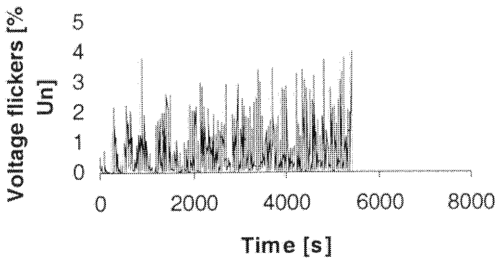


*Fig. 14. Voltage flickers (time course) calculated at TS „C" AC busbars (option 2).*

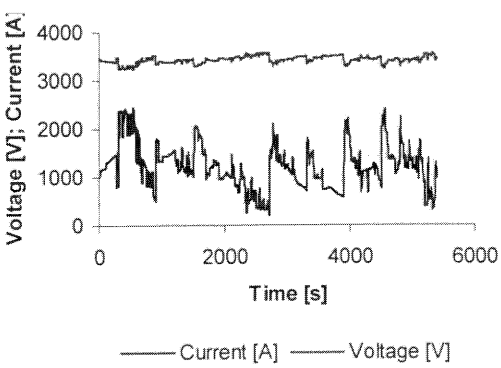


*Fig. 15. Load flow time course for TS „C" (option 2).*

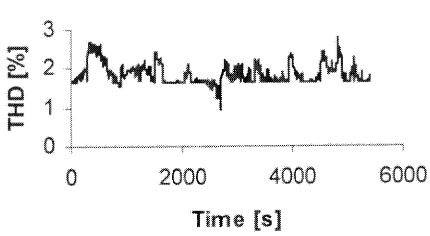


*Fig. 16. Voltage Total Harmonic Distortion (THD) calculated at TS „B" AC busbars (option 2).*

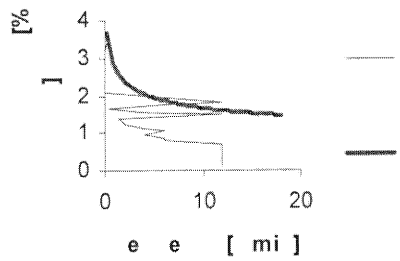

*Fig. 17. Voltage flickers calculated at TS „B" AC busbars and compared to criteria (option 2.1).*

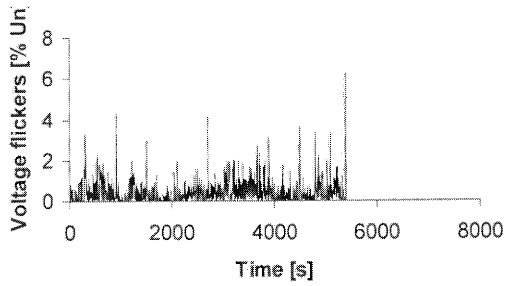


*Fig. 18. Voltage flickers (time course) calculated at TS „B" AC busbars (option 2).*

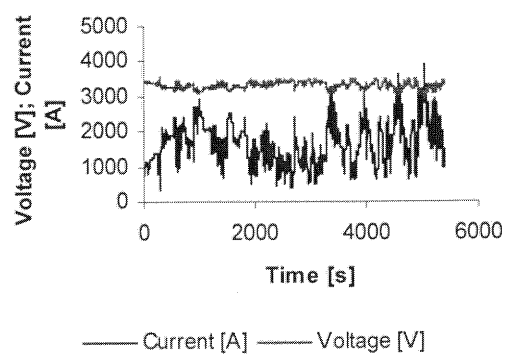


*Fig. 19. Load flow time course for TS „B" (option 2).*

## 4. MEASUREMENTS IN TSS

A set of measurements using a specialized equipment have been carried out in the operating traction substations with 6-pulse rectifiers. The results – 10 min RMS values are presented in the Figures 20-22 for a traction substation supplied by a short AC line.

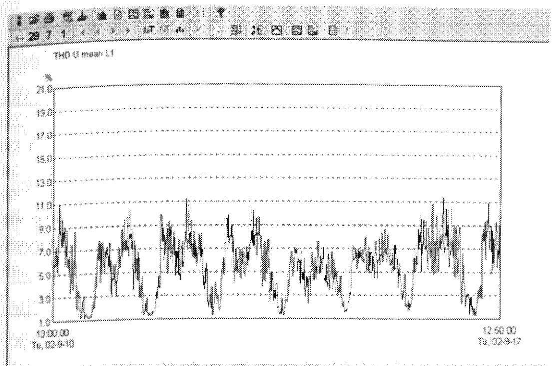

*Fig. 20 – THD U at 15kV AC bus-bars of a traction substation.*

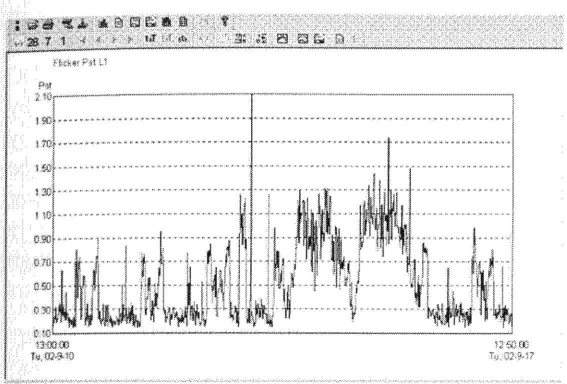

*Fig. 21- Pst flickers at 15 kV AC busbars.*

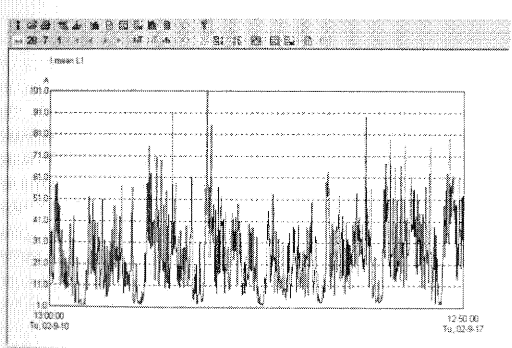

*Fig.22 - 15 kV AC phase current.*

while for a TS supplied by longer (8km) line in Figures 23 and 24.

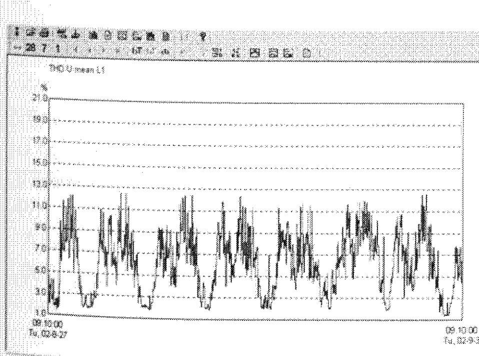

*Fig. 23 THD U at 15kV AC bus-bars of a traction substation.*

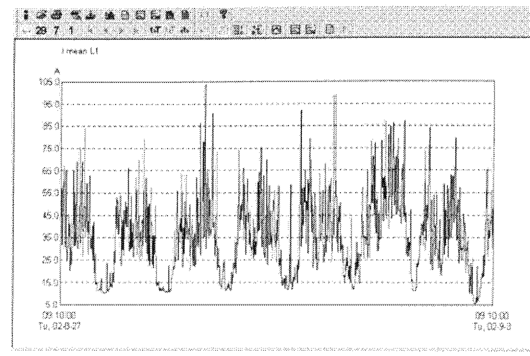

*Fig.24 15 kV AC phase current.*

In a case 12-pulse rectifiers are installed in TS there is practically now problems of THD U in a case ratio of a short-circuit level at AC busbars to load of TS is over 20-25 [4].

When this ratio is lower or resonance conditions are appearing (Fig. 25) THD U level at medium voltage may exceed limits defined by [3].(Fig.26), even the load of TS is low. But flickers of voltage (Fig. 27 i 28) are difficult to be overcome when medium voltage supply is applied and traction load high.

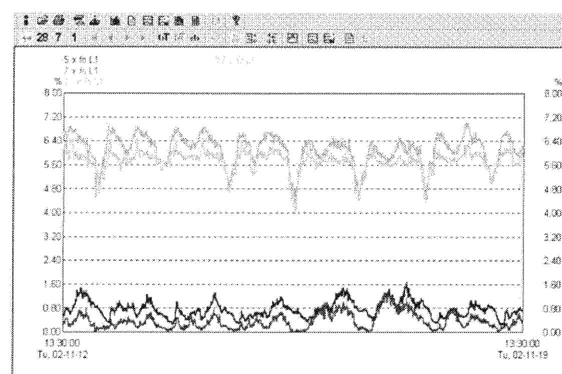

*Fig. 25 Harmonics at 15kV AC bus-bars of a 12-pulse traction substation (resonance conditions at AC side for 11-th and 13-th harmonics).*

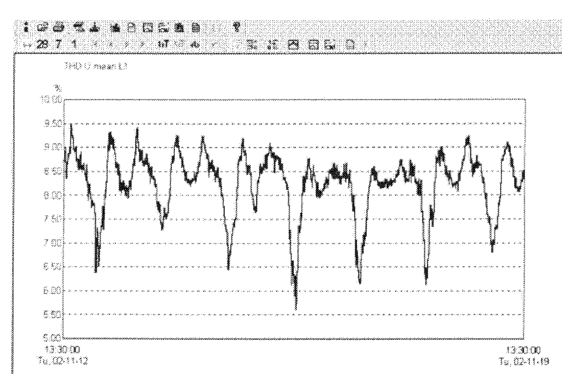

*Fig. 26 THD U at 15kV AC bus-bars of a 12-pulse traction substation (resonance conditions at AC side).*

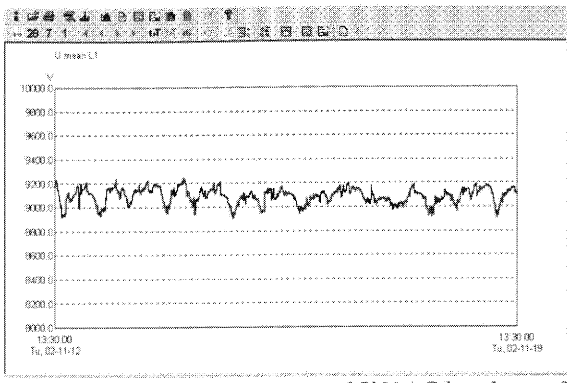

*Fig. 27 Voltage fluctuations at 15kV AC bus-bars of a 12-pulse traction substation.*

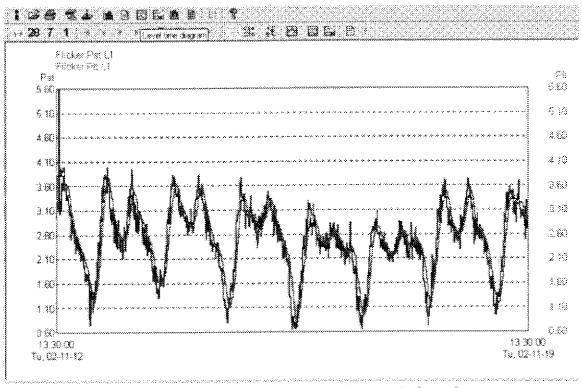

*Fig. 28 Pst flickers at 15 kV AC busbars.*

## 5. CONCLUSIONS

1. Modernization of the exiting power supply of the electrified railway line system due increase of traffic and rated power of locomotives create a need of undertaking feasibility studies of the technically possible design options.
2. The proposed solutions should be not only technically adequate but as well justified by economic and financial analysis. This creates restrictions on the power supply modernization variants taking into account not only traction but as well power supply schemes.
.3. Existing traction substations with 6-pulse rectifiers may cause significant harmonic distortions in supplying AC lines. The exchange them with 12-pulse rectifiers is a must not only in a case the power demand due to traffic increase is expected.
4. Schemes when two traction substations are supplied from the same AC busbars of PCC is the worst case of supplying TS as harmonic distortions are cumulated. But in a case distances between traction substations are not so big (Fig.3) it may be technically and economically justified to connect them to the same PCC via AC busbars of the neighboring substations, but only when they are equipped with 12-pulse rectifiers. Advantages of this scheme are:

- added power demand for two traction substations,
- no need to construct additional PCC,

while disadvantages:

- higher harmonic distortions and current changes (flickers) at AC busbars of PCC,

3. The presented method, based on the derived simulation software makes a useful tool during a design process to assess the level of disturbances that this solution will cause. The results of simulations have been verified with the measurements in traction substations, as only the measurements in real operating conditions will give the answer about the level of harmonics and flickers are not exceeded.
4. The performed simulation and measurements in traction substations by the authors allow to state, that harmonic distortion problem at AC side of 3kV DC traction rectifier substations may be overcome by installing 12-pulse rectifiers. But flickers caused by quick changes of traction currents are difficult to be limited when power demand is high and AC power supply system weak. The best, but the most costly solution is supplying of traction substations by high voltage (110kV) or dedication of MV AC busbars only for traction needs.

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