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DESIGN AND TESTING OF 25 kV AC ELECTRIC RAILWAY POWER SUPPLY SYSTEMS

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Preliminary notes

The paper describes the procedures implemented in the design and testing of the newly built traction substation, which is foreseen for the power supply of part of the electrical tracks in the area of Zagreb. The power capacity of the new traction transformer substation was determined according to the load flow calculation that was carried out for the period of maximal traffic time-table. During the period of test operation a number of measurements were conducted in order to testify technical performances of the substation, as well as to verify its impacts on the environment. Measurements of the power quality in the utility power network, which supplies the traction system, were conducted. Also, measurements of electrical and magnetic fields inside the traction substation and in its vicinity were undertaken.

Keywords: *AC electrified railway system, design and testing, simulation and measurement results analysis, traction substation*

Konstruiranje i testiranje 25 kV izmjeničnog sustava za napajanje električne vuče

Prethodno priopćenje

U članku su opisani potrebni koraci za konstruiranje i testiranje novoizgrađene elektrovučne podstanice koja je predviđena za napajanje jednog dijela prigradske pruge u željezničkom čvoru Zagreb. Potrebna snaga za napajanje elektrovučne podstanice određena je na osnovi elektrovučnog proračuna provedenog za maksimalni vozni red. Za vrijeme testnog rada elektrovučne podstanice su provedena potrebna mjerenja da bi se odredile tehničke karakteristike podstanice kao i utjecaj na okolinu. Provedena su i mjerenja kvalitete električne energije na prijenosnoj elektroenergetskoj mreži za vrijeme testnog rada podstanice. Također su dani rezultati mjerenja elektromagnetskog polja unutar i u blizini same podstanice.

Ključne riječi: *analiza simulacijskih i mjernih rezultata, elektrovučna podstanica, izmjenični elektrovučni sustav, konstruiranje i testiranje*

1 Introduction

Railway tracks in the area of Zagreb are electrified with the AC system of 25 kV. The network of electrified tracks together with the tractions substations (TS) and main passengers' stations (PS) is depicted in Fig. 1. Beside the existing three traction substations (Mraclin, Resnik and Zdencina) that have supplied the contact network of the Zagreb area in the past, the new traction substation Zapresic has been built in order to meet the growing energy demand. Also, the new suburban railway track between Zagreb and Bregana should be supplied from the new traction substation.

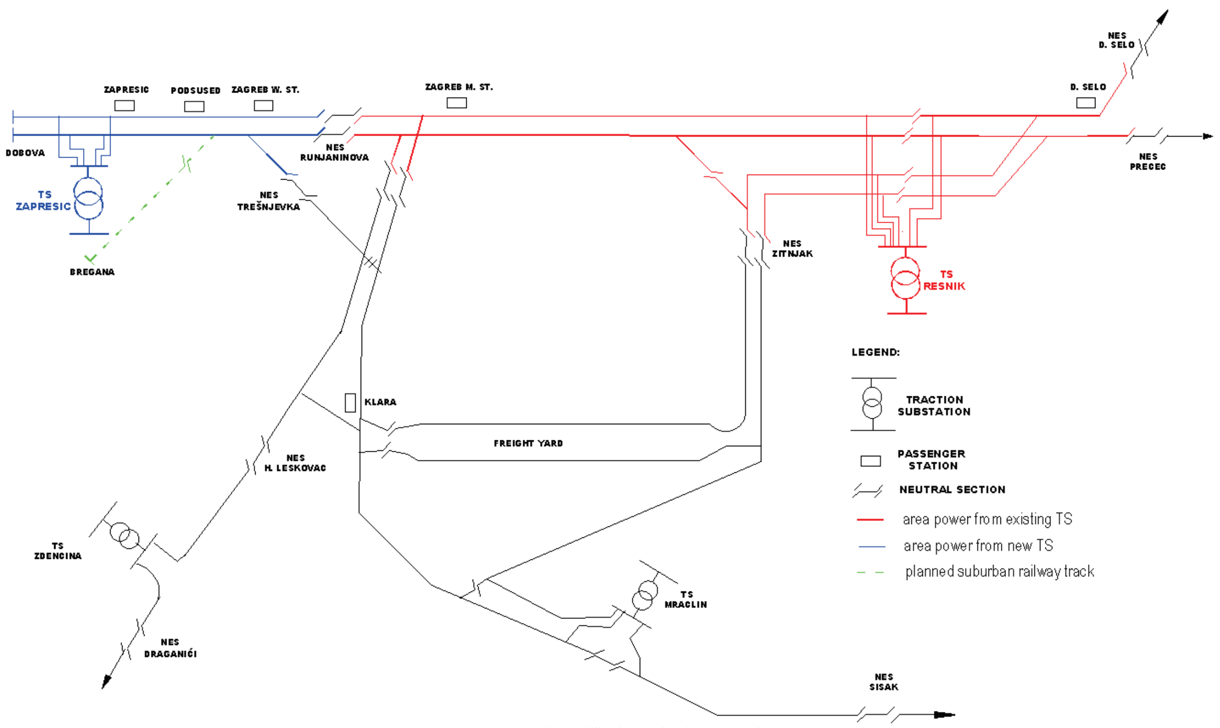

Figure 1 Electrified tracks in Zagreb

2 Analysis of traction power system

The purpose of the analysis is to calculate voltages, currents and power flows in the whole distribution system in order to evaluate the equipment ratings, estimate power requirements and to verify that the system will maintain a voltage level at the contact point with electrical vehicles sufficient to meet vehicle and system performance criteria.

Basic calculations are train movement simulation and load flow analysis. The whole calculation runs in time steps for the desired time period. The train movement simulator gives the exact locations, active and reactive power demand of each train in every time step. This enables the power system simulator to determine the electrical conditions in the power utility distribution system, i.e. current flows in elements, voltages, power flows, and energy [1].

To determine the energy consumption of a traction unit, the resistive effort of a certain section of the railway track must be first calculated and known. Therefore, the input data necessary for the calculation are the railway track profile parameters, planned velocities for each railway track section, as well as characteristics of trains and locomotives [2].

The electric network is formed from data obtained by the train movement simulator on the observed railway track. It is possible to form electrical network and simulate the traffic in the selected time period by step by step calculation. The forming of electrical network in railway system is specific because the scheme of powering is continuously changing; i.e. some trains enter and some others leave the powering area. A customary manner of operation for this system is radial operation (single substation), but this algorithm and the corresponding computer program were also developed for the case of supply from a parallel operation of substation [3].

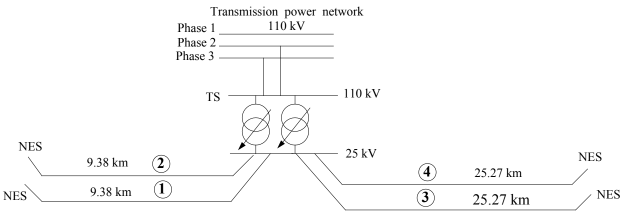

Figure 2 Power supply scheme of TS

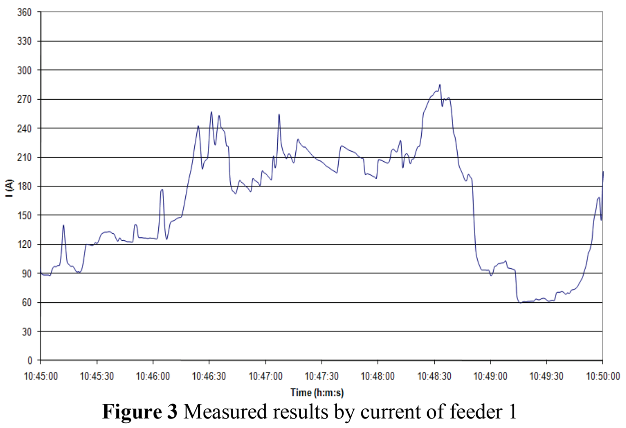

Figure 3 Measured results by current of feeder 1

2 .1 Verification of the calculation algorithm

The developed algorithm for numerical simulations was first tested for an existing traction substation. Measurements of currents, voltages, electrical power and energy were conducted at the 25 kV side of the 25/110 kV substation, connected to the 110 kV power network. Lengths of the railway track powering from this transformer substation are around 10 km and 25 km respectively (Fig. 2). The load flow calculations were performed for the period in which 1 freight train (weight mass of 750 t) and 6 electro-motor trains (weight mass of 176 t) were travelling on the railway track [4].

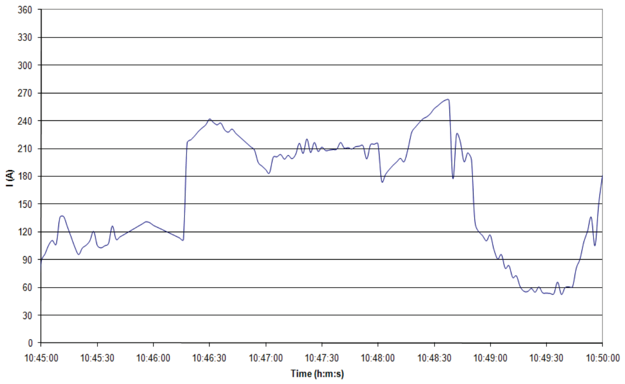

Figure 4 Calculated results by current of feeder 1

The comparison of results gained by the computer simulation and measuring data for the existing traction substation (railway track 1) is depicted in Fig. 3 and Fig. 4.

2 .2 Simulation of traction power supply

Among different computations conducted, below are shown results of simulation for the new TS which supplies a part of the existing network and the new suburban railway track that is intended for passenger transport only. Simplified longitudinal profile of the railway track is shown in Fig. 5.

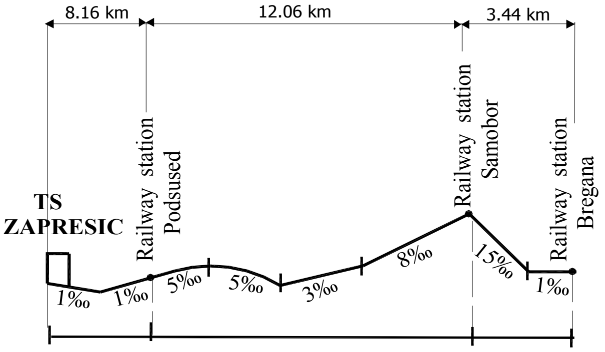

Figure 5 Simplified longitudinal profile for railway track

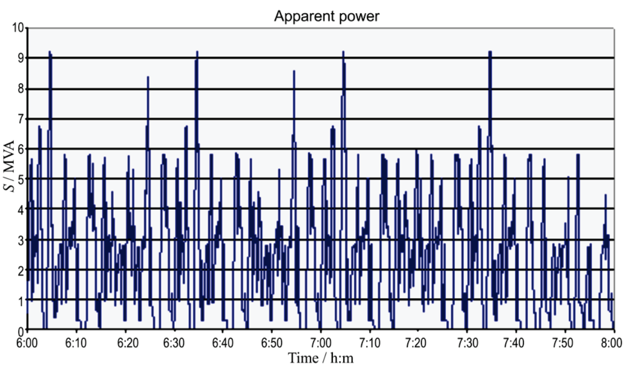

Figure 6 Power demanded for supply of railway track Podsused – Bregana

Load flow calculation was conducted for the maximum time-table graph (from 6 AM to 8 AM). Feeding of the railway track is carried out by the contact line system, which has an impedance of (0,181+j0,447) Ω/km. The cross-sections of the contact conductor and the suspension wire are 100 mm^2 and 75 mm^2 respectively. Length of railway track powering from the traction substation is 23,8 km.

Two power transformers whose rated power is 15 MVA, for each of them, supplies the track. The results obtained by the calculation are shown in Figs. 6, 7 and 8.

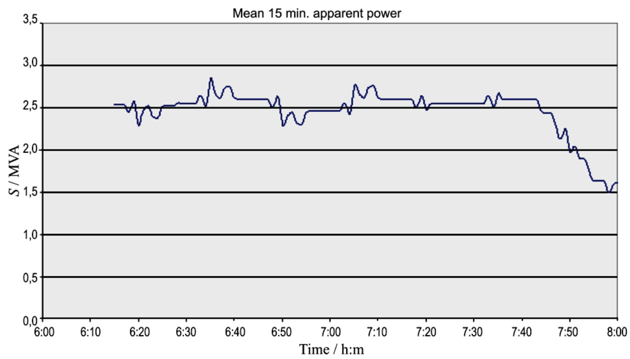

Figure 7 Mean 15 min. power demand for supply of the suburban railway track Podsused – Bregana

The energy consumption for two hours period demanded for the power supply of railway track Podused - Bregana is shown in Fig. 8. The parameters of the equipment in the new substation were determined on the basis of conducted simulations.

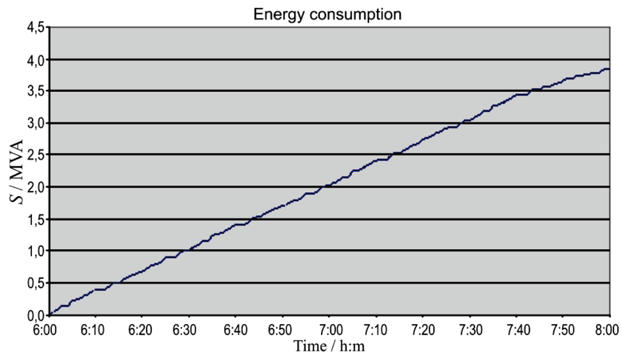

Figure 8 Electrical energy demand of TS Zapresic that supplies the railway track Podsused – Bregana

3 Measurements during test operation

After the construction had been accomplished different tests and measurements were carried out. Some typical measuring results in testing of power quality and electromagnetic fields will be described next.

3.1 Power quality testing trial work

The 25 kV traction substation (TS) is connected to the 110 kV transmission power network by two traction transformers 110/25 kV. The nominal power of each traction transformer is 15 MVA and it was determined in accordance with results of the conducted simulations. The single line diagram of the 110 kV switchgear and points of connection of measuring equipment is shown in Fig. 9.

Because of facts that the TS is connected to transmission network only in two phases (Phase 2 and Phase 3), operational characteristics of locomotives (diode, thyristor and another type) and changeable consumption of active and reactive power (start, acceleration, breaking) it is very important to measure the power quality in point of the connection to the transmission power network.

Considering that the TS is connected to the transmission network, from which the power distribution network at the 20 kV level is also powered, it is important to note that the measured power quality does not originate only from the TS, but also from other consumers connected to the site at the 20 kV level.

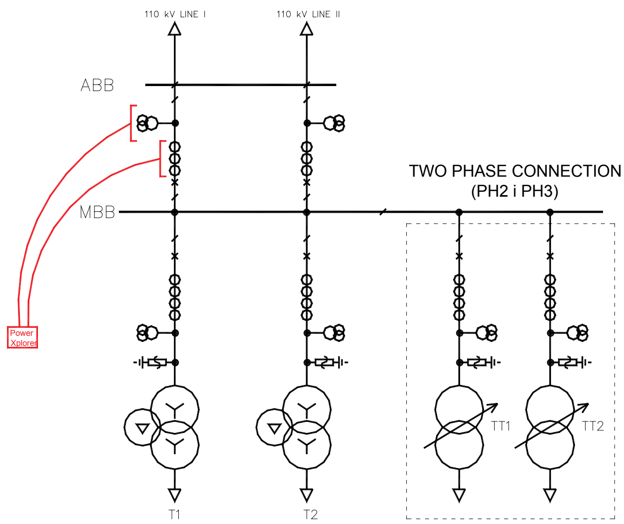

Figure 9 The single line diagram of 110 kV switchgear (red - instrument connection)

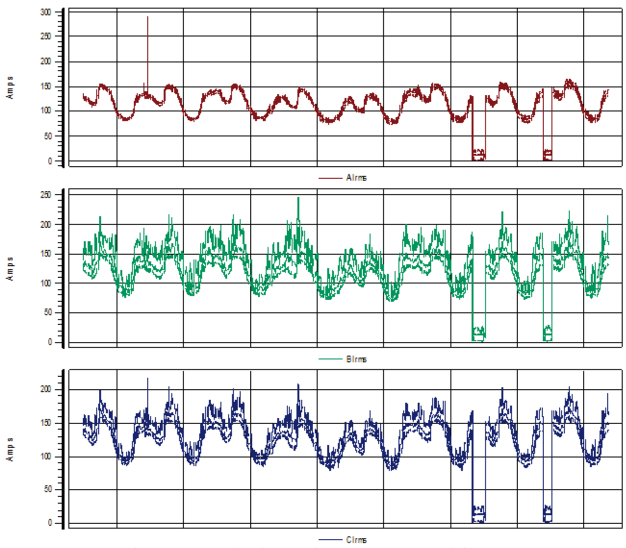

Figure 10 The currents in three phases (measured from 23.01.2008 11:35:07,0 to 31.01.2008 08:59:54,0)

Using power quality instrument, the next indicators of power quality were measured [5]:
- amount of voltages in each phase;
- the voltage unbalance;
- the current unbalance;
- harmonics;
- flickers;
- voltage sags;
- voltage swells;
- overvoltage's;

- power interruptions.

Fig. 10 shows results of current measurements (8-days period). There were some switching operations, in the period of the measurement, what is seen on Tuesday and Wednesday in Fig. 10.

Based on the measurements in a given period in 110 kV switchgear, the following can be concluded:

- The voltage unbalance in the whole observed period is less than the allowable 1,5 %;
- Values of higher harmonics are significantly less than the allowable [6];
- Amounts of higher harmonics are also significantly less than the allowable value;
- Amounts of flickers in more than 95 % of the observed time are much smaller than the allowed value of 1.

3.2 Electric and magnetic fields

Measurements of electric and magnetic fields were conducted inside the traction substation and also at the near passenger station. Position of measurement points at the railway station is depicted in Fig. 11.

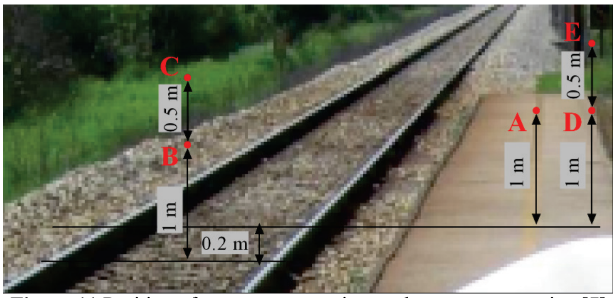

Figure 11 Position of measurement points at the passenger station [7]

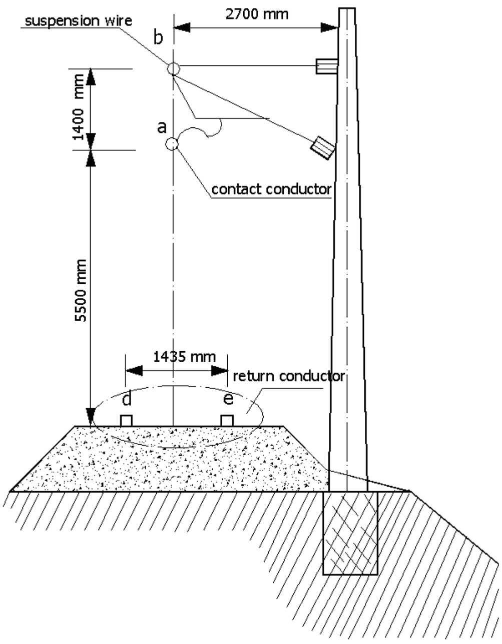

Figure 12 Cross-section of the pole of the contact line system AC system 25 kV

Electric and magnetic fields were also calculated and compared with measured values. Cross-section of the pole of the contact line system is shown in Fig. 12.

Results of measurements of magnetic induction at the passenger station and the current of feeder during the measurements are shown in Fig. 13.

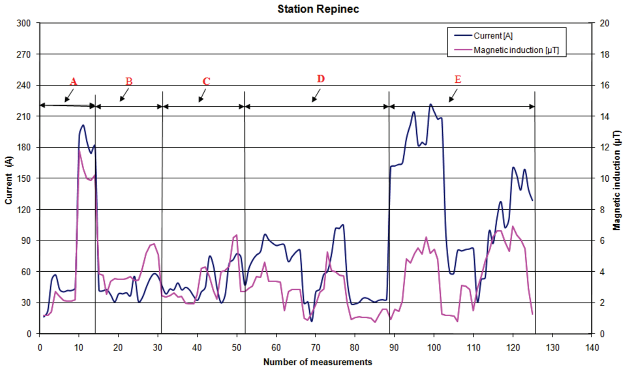

Figure 13 Result of measurements: magnetic induction at PS and the current of feeder at h = 1,5 m [8]

Computer simulations of the magnetic induction in the proximity of the contact line system for different values of the feeder current were conducted. Results of calculation of magnetic induction for the feeder current of 600 A is depicted in Fig. 14.

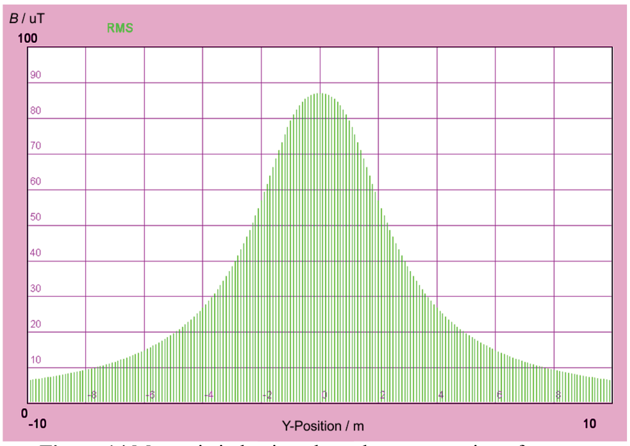

Figure 14 Magnetic induction along the cross-section of contact network [9]

Results of measurements of magnetic induction on a fence of TS and the total current of TS during the measurements are shown in Fig. 15.

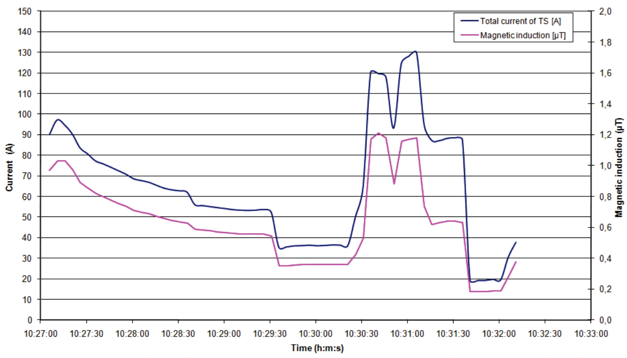

Figure 15 Results of measurements of magnetic induction on the fence of TS and the total current of TS at h = 1,5 m

The maximum measured value of magnetic induction at the passenger station was 12 μT that is the lower value than the permitted limit level, which exceeds 100 μT in Croatia.

Results of measurements of electrical fields at the passenger station at measuring points depicted in Fig. 11 are shown in Tab. 1. The maximum measured value is lower than the permitted limit level in Croatia of 5 kV/m.

Table 1 Results of measurements of electrical fields strength

Measurement points	Voltage at the 25 kV side of TS /kV	Strength of electric field / kV/m
A	25,74	1,27
B	25,87	1,55
C	26,38	1,70
D	26,15	0,80
E	25,95	1,02

4 Conclusion

Some steps in the design procedure and testing of a new traction substation are presented in the paper. The developed algorithm for the simulation of power load flow has been tested in the existing network and then implemented for the determination of the rating parameters of the substation equipment.

After the new substation was accomplished, power quality measurements have been conducted and the indicators of power quality were measured such as: amount of voltages in each phase, voltage and current unbalance, harmonics, flickers, voltage sags, voltage swells, overvoltages, power interruptions. The measured values were bellow permitted limits.

Also the measurement of electric and magnetic fields inside the substation and at the passenger station near the substation were conducted. These measurements showed good agreement with the values that were previously computed.

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