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Power quality analysis in electric traction system with three-phase induction motors

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ABSTRACT

Three-phase induction motors are widely used in electric traction systems. The impacts of the traction vehicles equipped with three-phase induction motors on power quality are much different from the impacts of vehicles with DC traction motors. In this paper, the effects of the traction vehicle operation with three-phase induction motors on power quality in a 110 kV transmission network are investigated.

The electric traction system 25 kV, 50 Hz and the traction vehicle with three-phase induction motors were modeled including AC/DC rectifier and DC/AC inverter based on IGBT technology. The parameters of those power electronic elements directly determine the current and voltage waveforms, and consequently power quality parameters.

Measurements and calculations of power quality parameters were presented. Three operation modes of traction vehicle were considered including acceleration, constant drive and regenerative breaking. During the test drives, the values of total harmonic distortion, unbalance, flicker and power factor were obtained.

1. Introduction

Electric railway systems are essential for the transport of people and goods. Numerous advantages of electric railways have been proven in comparison with other forms of transport, from reliability and safety to the speed and comfort [1]. The development of societies and economics entails the improvement of railways. The most important railway transportation routes are electrified which makes this system more competitive and environmentally more acceptable [2].

An electric railway is a single phase consumer [3]. Operations of traction vehicle may have significant effects on power quality parameters in the power system [4]. One of the most widely used railway electrification systems is 25 kV, 50 Hz. This system is powered from the electric power transmission system and it supplies traction vehicles through contact network. Voltage and current waveforms in the railway system directly depend on the type of traction vehicle, its characteristics and electrical properties [5]. Electric traction vehicles are commonly equipped with DC motors or three-phase (3f) AC motors [6]. The advantages of 3f induction motors are manifested in possibility for energy recovery during braking or operating on downhill and simplest maintenance. Electric railway system has an influence on systems that ensure reliability of the system (communication subsystem), but also on the systems in the vicinity which are sensitive to disturbances [5,7,8]. Current and voltage waveforms of different traction vehicles cause different disturbances on nearby sensitive systems.

The power transformer at traction vehicle is connected to AC/DC rectifier which is connected to DC link (Figs. 1 and 2). DC voltage is converted by DC/AC inverter to 3f AC voltage and supplies 3f AC induction motor. Power electronics elements, rectifier and inverter consist of thyristors or IGBTs [9]. The power quality parameters and the waveforms of voltage and current are measured on the 110 kV busses. During the measurements only one locomotive was in operation on a feeder supplied from traction substation. That ensures that the other traction vehicles have no impact on the measured values because of their electrical distance.

All measurements were performed during acceleration, constant drive and regenerative braking of electric traction vehicle. Waveforms of electric parameters in different operation modes are compared and deviations from nominal values are found according to the applicable standards [10,11]. The measurements and analysis of power quality parameters in traction substation during the operation of locomotive equipped with 3f induction motors were presented.

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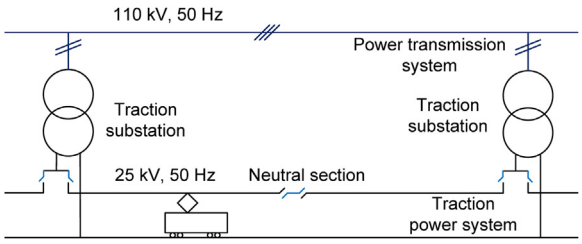

Fig. 1. Electric traction system.

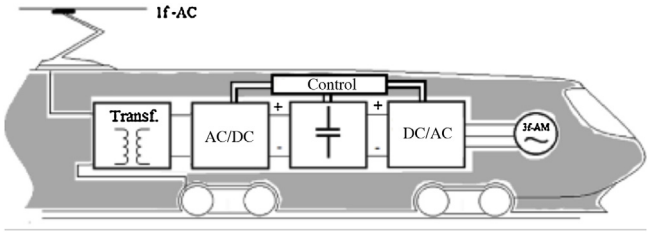

Fig. 2. Electric traction vehicle with an induction motor.

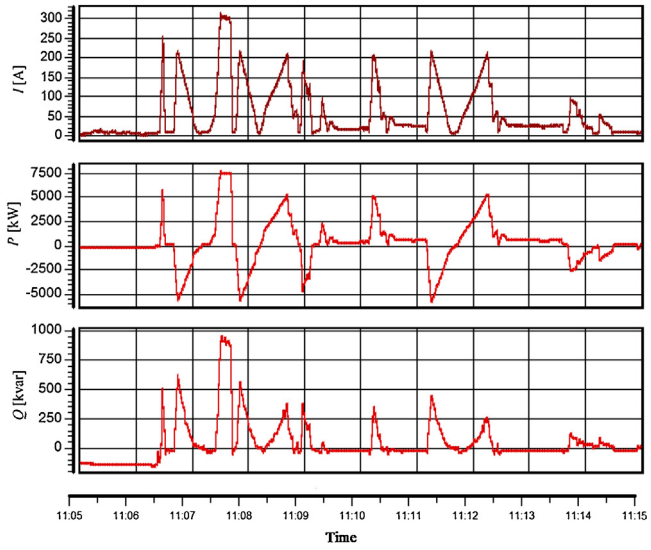

Fig. 3. RMS current, active and reactive power of electric traction vehicle with induction motors.

2. Operation of traction vehicles with 3f induction motors in electric railway system 25 kV, 50 Hz

The operation of the single-phase 25 kV (50 Hz) electric traction system is significantly different from the electric power system which supplies it [3].

The electric traction system is supplied from electric power system through power transformers located at traction substations. These transformers are connected to two phases of the power transmission system. The traction power supply network is separated by neutral section to the independent sections which are supplied from different traction substations. Fig. 1 shows a principle connection scheme of the 25 kV, 50 Hz electric traction system to 110 kV transmission network.

Electric traction vehicles are powered from contact network via a pantograph and a power transformer that adjusts the 25 kV voltage to a value suitable for induction traction motors (Fig. 2).

In this paper, multi-system traction vehicle supplied by 25 kV, 50 Hz system was analyzed. The nominal drive power of one unit is 6.4 MW and heating power is 900 kV A [12,13]. Fig. 3 shows the measured effective values of current and active/reactive power on 25 kV side. The values of current and power change stepwise and depend on the operation mode. The measured supply current exceeded 300 A, while at the same moment the maximum measured active and reactive powers were 7.5 MW and 950 kvar, respectively. The measured reactive power had a permanent positive sign, whereas active power can have a both positive and negative sign, depending on power flow direction. In the periods when the value of active power is positive, energy flows from the power substation to the traction vehicle while a negative sign indicates the opposite flow of energy. The maximum active power during recuperation braking (energy recovery) was 5.5 MW and has been reached at the moment when the current was 215 A and reactive power was 440 kvar. As expected, the maximum power that can be recovered was less than the maximum power that the vehicle used for the acceleration.

3. Model of traction vehicle with induction motors

The model of electric multiple unit of 2 MW continuous power was developed in the ATP software and it includes power transformers at the substation and on the vehicle, IGBT converters, a DC link and an induction motor with rated power 525 kW.

The impedance of 110/25 kV power transformer referred to the 110 kV side is $R = 0.5\,\Omega$ and $L = 4$ mH (7.5 MW, $u_{k\%} = 10\%$). Contact network impedance is $0.181 + j0.447\,\Omega$/km. The DC link was modeled by a capacitance ($C = 36$ mF) and an inductance

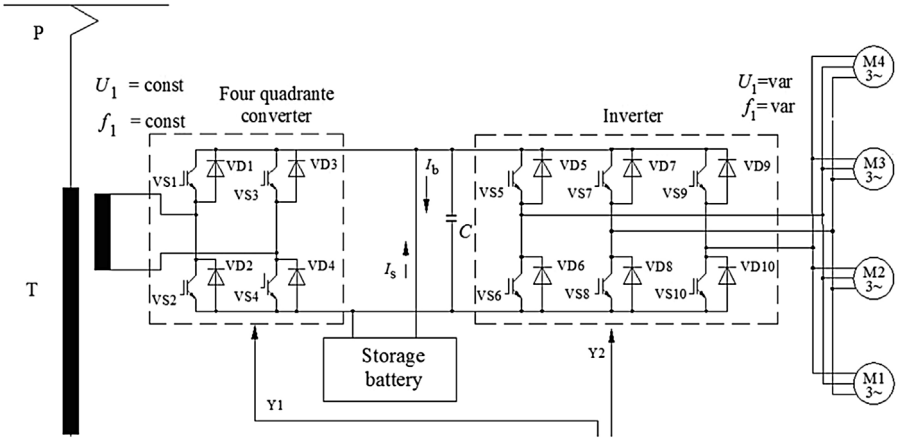

Fig. 4. Electrical scheme of traction vehicle with induction motors [14].