Measuring and Analyzing Power Quality in Electric Traction Systems

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ABSTRACT

Power Quality phenomena in a broad sense, stationary and transient, are considered focusing on railway applications: dc and ac traction lines are considered, identifying the main sources (fixed, like substations, and moving, like vehicles), their characteristic emissions, how they propagate and combine along the traction lines and back to the three-phase ac supply lines. The analysis covers the railway standards applicable to the traction line and the industrial standards applicable to the ac feeding lines. The peculiarity of railway applications, that is the presence of moving distorting loads interconnected by a non-ideal transmission line and characterized by variable operating conditions and by the superposition of multiple sources with different dynamics, requires specific processing, analysis and visualization methods, that are addressed by means of examples based on real data.

Keywords: Electric Traction Systems, Non-Ideal Transmission Line, Power Quality, Railway Standards, Variable Operating Conditions

1. INTRODUCTION

Power Quality (PQ) is an all-comprehensive term that includes several conducted phenomena at low and medium frequency, steady and transient, for the definition of which reference may be made to (Rey & Martinez Muneta, 2011; Kimbark, 1971; Warne, 2005). An electric transportation system represents a peculiar environment for the application of the PQ concepts; depending on the type of system (heavy railways, light railways, metros, tram and trolley bus lines) and the traction supply (dc or ac, low or high voltage, scheme of supply, etc.) PQ phenomena can take a different aspect, assume a different role and be more or less relevant in terms of intensity, propagation and covered area, caused interference and side effects, and ease of compensation or filtering. Moreover, we may distinguish between PQ phenomena that are relevant for the same trains and vehicles along the traction line, and PQ phenomena that propagate at higher voltage levels, being of concern for other loads inside the same railway system or at further distance along the High Voltage (HV) or Medium Voltage (MV) network used to feed the Electric Sub-Stations (ESSs). As per the relevant railway standards

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(EN 50163, 2004; EN 50388, 2005) and the general knowledge of railway supply behavior, we can outline the relevant PQ phenomena as:

- **Harmonics:** Whose frequency is related by an integer ratio to the supply fundamental, that may be subject to some shift in frequency in particular conditions of heavy load and major supply transients (EN 50163, 2004; EN 50388, 2005; EN 50160, 2010; IEEE Std. 519, 1992; Ogunsola & Mariscotti, 2012);

- **Inter-harmonics:** In principle appearing as narrowband frequency components with no integer ratio with the supply fundamental; they are in general the byproduct of static converters operating on on-board loads, and in particular traction motors, so experiencing a variable reference fundamental and thus moving along the frequency axis, while beating with the pre-existing harmonics;

- **Flicker:** Seen as the resultant low frequency modulation of the amplitude of the fundamental of the three-phase supply system feeding the ESSs (Ogunsola & Mariscotti, 2012); the modulation is caused by the variable power absorption related to the load mix of trains and vehicles following their respective timetables under quite a variable operating profile, including acceleration with intensive power absorption, coasting with negligible power absorption and braking with regenerative power sourcing; trains and vehicles are not susceptible to flicker because it lies widely within the tolerances and variability of the supply system they have been designed for;

- **Reactive power flow:** Along the traction line and over the supply network due to the interaction of the many static converters located at ESSs and on-board; since there is a relevant impact on line sizing, voltage drops and power losses this aspect is well disciplined in terms of limits and requirements, and as a consequence of implemented countermeasures, such as limiting the power factor of trains depending on the absorbed power (EN 50388, 2005) or compensating the ESSs on the three-phase side by special transformers, capacitor banks and filters, controlled reactors and active compensation systems (Ogunsola & Mariscotti, 2012);

- **Various types of transients:** Like voltage swells and sags, overvoltages, etc. highly depending on the characteristics of the power supply system and loads, and in some cases referred to the way the power is drawn from the traction line supply, that is through the sliding contact of a pantograph (for overhead or catenary systems) or sliding shoe (for third rail systems); the relevance of these phenomena is mostly related to the traction line and to the caused transients and associated transient spectral components, that may trigger oscillations and produce interference to signalling systems (CLC/TS 50238-2, 2010).

Of course, the characteristics of such PQ phenomena, in terms of amplitude, frequency range and time-frequency behavior require specific measurement techniques as well as post-processing methods, in order to both meet standards’ specifications and limits, and derive consistent representations for further analysis (Mariscotti, 2011). DC railway systems exhibit some peculiar characteristics that may necessitate slight modifications to normally accepted analysis methods commonly applied to ac systems (Mariscotti, 2012a).

In the following sections all these aspects are considered in more detail with the help of some practical examples and further referencing available literature. The focus is on the methods adopted for the processing of measurement data and the presentation of results, in particular for very different phenomena and purposes, frequency and time scales. The normative references, the main elements and the architecture of traction power supply systems and the definition of phenomena are briefly described as well.
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