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 experienc-
  ing a variable reference fundamental and thus moving along the frequency axis, while
  beating with the pre-existing harmonics;

- **Flicker**: Seen as the resultant low fre-
  quency modulation of the amplitude of
  the fundamental of the three-phase supply
  system feeding the ESSs (Ogunsola & Mar-
  iscotti, 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 ac-
  celeration with intensive power absorption,
  coasting with negligible power absorption
  and braking with regenerative power sourc-
  ing; 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 convert-
  ers 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 depend-
  ing 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 refer-
ences, 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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