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Simplified models of a single-phase power electronic inverter for railway power system stability analysis—Development and evaluation

Steinar Danielsen*, Olav B. Fosso, Marta Molinas, Jon Are Suul, Trond Toftevaag

Department of Electric Power Engineering, Norwegian University of Science and Technology, N-7491 Trondheim, Norway

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ABSTRACT

Use of power electronic equipment has increased and introduced new dynamical phenomena in power systems. For example, new electric rail vehicles (locomotives) equipped with modern power electronic traction chains have caused situations of low frequency power oscillations and instability in single-phase railway power supply systems. This paper presents the development and implementation of an instantaneous value model and simplified fundamental frequency (RMS) models of such an advanced electric rail vehicle in order to investigate their representation of low-frequency dynamics. The dynamical behaviour is studied by use of both time-domain simulations and linear analysis (eigenvalues) and the degree of simplifications regarding controller dynamics and power system dynamics are presented and discussed. An enhanced RMS model is tested in order to account for the impact of fast current dynamics on the low-frequency behaviour. The results show that this enhanced model is corresponding more closely to the instantaneous value model than what can be obtained by the traditional RMS simplifications and indicate that current dynamics should be included in stability studies involving power electronic inverters.

1. Introduction

Use of power electronic components in various power systems has expanded during recent years [1]. This is especially seen in power systems where electric motor drives are the dominating loads or renewable energy sources are present [2]. The use of power electronic converters with modern digital control techniques opens a new world of possibilities.

This is also the case in railway power supply where there is demand for fast control of electric motors by light-weight and small-size equipment in order to increase the running performance of electric trains. Almost all new electric (locomotives) today are equipped with three-phase asynchronous motors [3]. In a single-phase AC traction power system, the vehicle interface to the rest of the power supply is a power electronic converter behind an impedance as shown by the line inverter and main transformer in Fig. 1. These new technologies raise new questions about electrical system compatibility [4].

One particular issue that has been focused in the electrical railway community during recent years is power oscillations at low frequency, typically in the range of 0.1–0.3 times the fundamental frequency, that lead to power system instability due to lack of damping. The power electronic based locomotives may interact unfavourable with each other [5] or with the power system components, such as rotating synchronous–synchronous frequency converters [6], making the power system unstable.

In a traditional three-phase power systems with mainly electric machines and passive loads, it can be argued that low-frequency stability studies by time-domain simulations and linear analysis can be performed in fundamental frequency RMS (root-mean-square) mode instead of by time-domain simulations with instantaneous values of voltage and current values [7]. In a power system with dominating non-linear components, and in single-phase system particularly, these traditional tools may not be fully valid any more [8].

It would be of great interest and benefit if already established and classical methods for power system stability studies can be used in systems with power electronic components as well. Hence, the aim of this paper is to investigate to what extent traditional power system modelling of a power electronic inverter reflects low-frequency phenomena in a single-phase system.

This paper presents and evaluates models of the grid interface for an advanced electric rail vehicle (inverter vehicle) as shown in Fig. 1. The models are developed and implemented in a traditional power system simulator, Simpow [9], in both single-phase instantaneous value mode and fundamental frequency (RMS) mode. After an introduction to the fundamentals for single-phase instantaneous values and RMS modes in Section 2, the vehicle and its model are

* Corresponding author. Tel.: +47 91656304; fax: +47 73594279.
E-mail address: steinar.danielsen@elkraft.ntnu.no (S. Danielsen).

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