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Input impedance of multi-drive traction vehicle

Abstract*. The tractions vehicle's input impedance Z_{in} is an important parameter from the point of view of compatibility in electric traction system. The article presents a simulation analysis and comparison of input impedance of two types of traction drive systems: a drive system with a single inverter and a drive system with two parallel inverters cooperating with one input filter. The analysis was carried out for 50 Hz impedance, which acceptable minimum level is defined in the relevant regulations.*

Streszczenie. *Impedancja wejściowa elektrycznego pojazdu trakcyjnego Z_{in} jest ważnym parametrem z punktu widzenia kompatybilności w trakcji elektrycznej. W artykule przedstawiono symulacyjną analizę i porównanie impedancji wejściowej dwóch trakcyjnych układów napędowych: układu z pojedynczym falownikiem oraz układu z dwoma falownikami współpracującym z jednym filtrem wejściowym. Analizę przeprowadzono dla impedancji 50 Hz, której dopuszczalny minimalny poziom jest określony w odpowiednich przepisach.* ***Impedancja wejściowa pojazdu trakcyjnego z wieloma napędami***

Słowa kluczowe: Impedancja wejściowa, kompatybilność, falownik napięcia, trakcja elektryczna.
Keywords: Input impedance, compatibility, voltage source inverter, electric traction

Introduction

The 3 kV DC electric traction system consists of a set of sub-systems responsible for such functions as:
- electrical power delivery to traction vehicles,
- transmission of information between vehicles and the control checkpoints,
- safety and railway traffic control station,
- information for passengers,
- and others.

the traction power supply system is responsible for the electrical power delivery. In the 3 kV DC system it consists of [1]:
- traction substation (TS) [2] and a type of a DC side filter [3],
- contact line (CL),
- return circuit(RC),

The closure element for the electric circuit of power supply system and also the receiver of energy is an electric traction vehicle. A scheme of a comprehensive system model is presented in Fig. 1 (Traction substation TS and electric traction vehicle ETV presented as a complex models of the semiconductor devices, designed for the time domain simulations, are marked in Fig. 1 as "a")[6].

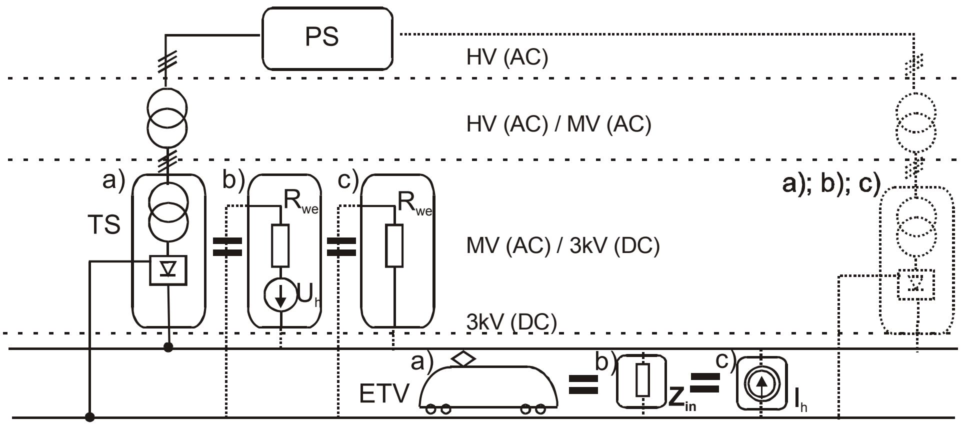


Fig. 1 Scheme of 3 kV DC electric traction power supply system. HV - high voltage level; MV - medium voltage level; PS - power system; TS - traction substation; ETV - electric traction vehicle

Currently, the vast majority of modern traction vehicles powered from DC voltage is equipped with asynchronous motors fed from voltage source inverters (VSI). That is the reason why the traction vehicles are known to be a non-linear receiver which constitutes a source of current harmonic which flows through rails to the traction substation [4], [5]. It creates disadvantageous operating conditions for devices of the traffic control system connected to the rails, named track circuits. This type of interaction analysis must be carried out on the equivalent model of a power supply system, in which the traction substation is modelled as internal resistance R_{we} and traction vehicle as the source of the assumed current harmonic spectrum (Fig. 1 - elements marked with "c"). On the other hand, traction substation equipped with rectifiers of significant power (about mega watts) is considered to be a source of voltage harmonics. In the equivalent circuit scheme of traction power supply system, these voltage harmonics are applied to the impedance which is a serial connection of catenary, rails and traction vehicle impedances (Fig. 1 elements marked with "b").The currents harmonic generated in such a way, are dependent on the modulus of the elements' impedances. The catenary and rail impedances, depends on the harmonic frequency and distance of the vehicle to the substation [7]. At the same time the input impedance of the traction vehicle may vary. The problem of variability of traction vehicle's input impedance was already raised in the 80's [8] at the example chopper fed drive. Similarly, a number of studies [9], [10], [11] have demonstrated that there are conditions in which the input impedance of the VSI drive system may change its value with the change of the operating point of the traction inverter used to drive the traction motors. To protect low-frequency track circuits the minimum value of the traction vehicles' input impedance of 50 Hz of 0.3 Ω is determined in the standard EN 50388 [12]. For this reason, any changes to the value of Z_{in} should be analysed and taken into account at the traction vehicles' designing stage.

In this article ones take under consideration the problem of the influence of the traction inverters configuration on-board the vehicle on fluctuations of 50 Hz input impedance which is included in standard [12]. *The article presents a simulation analysis and comparison of input impedance of two types of traction drive systems: a drive system with a single inverter and a drive system with two parallel inverters cooperating with one input filter.*

Simulation model

The main object of the research is the simulation model of asynchronous motor fed with 500 kW, two-level voltage source inverter (Fig. 2 a). The developed simulation model is designed to determine the input impedance of the drive systems in steady states and has been verified by laboratory measurements [13]. The basic condition that must be met during the study is the lack of a 50 Hz harmonic in the current spectrum generated by the drive system. The input voltage from the the power supply system side is modeled as an ideal 50 Hz sine voltage source with an amplitude of U_h = 10V connected in series with a DC voltage U_{DC}. A second model consists of two identical synchronized inverters connected to the same input filter (Fig. 2 b).

a)

b)

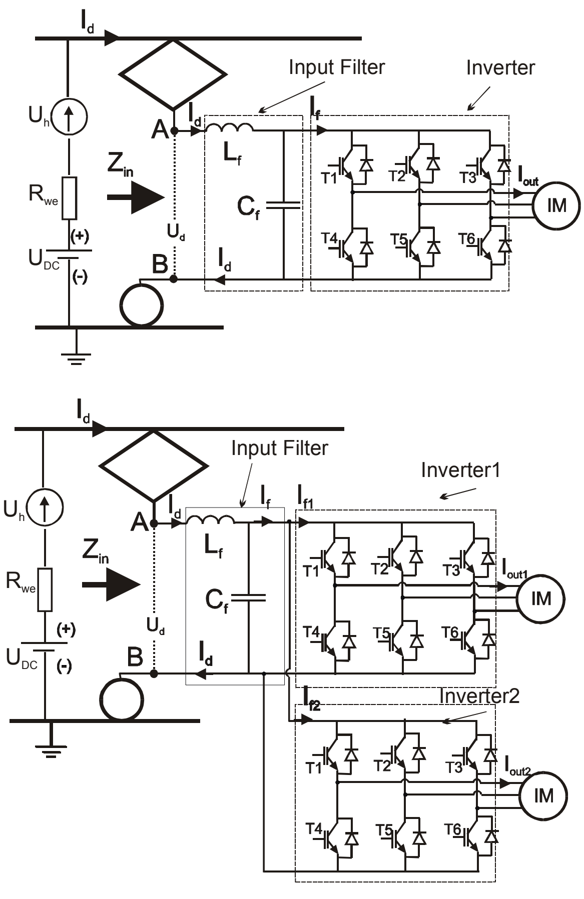


Fig. 2. Scheme of the simulation model a) a single inverter b) double inverter

In the model of the drive system the model of the stopped induction motor designed for harmonics analysis was used. A scheme of the asynchronous motors' one phase is shown in Fig. 3.

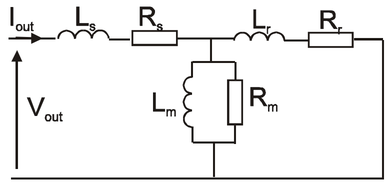


Fig. 3. Scheme of the model of a three-phase asynchronous motors' one phase

The assumed parameters of the drive system model are listed in Table 1.

Table1. Parameters of the drive system model

Parametr		Value
Input filter's inductance	L_f	8.7 mH
Input filter's capacitance	C_f	4mF
Per phase stator winding resistance	R_s	0.107 Ω
Per phase rotor resistance	R_r	0.07 Ω
Per-phase stator leakage inductance	L_s	1.565 mH
Per-phase rotor leakage inductance	L_r	1.605 mH
Magnetizing inductance	L_m	53 mH
Magnetizing resistance	R_m	1500Ω

Results of determination of the drive systems' input impedance

The traction vehicle's input impedance Z_{in} (f50Hz) of selected frequency is calculated as the quotient of the rms value of 50 Hz voltage harmonic U_d (Fig. 2) and rms 50 Hz current harmonic I_d determined for the vehicle's input terminals A-B. Assuming that the current and voltage waveforms are discrete signals and fulfill the Dirichlet's conditions, to designate Z_{in} components the Fourier transform (FFT) can be used. Then, the input impedance $Z_{in}(f)$ (seen from the terminals A-B - Fig. 2) can be written in complex form:

$$(1)\quad \underline{Z_{in}}(f) = \frac{FFT(U_d(t))}{FFT(I_d(t))} = \mathrm{Re}\{Z_{in}(f)\} + j\,\mathrm{Im}\{Z_{in}(f)\}$$

where: $U_d(t)$ - voltage signal determined at the input of the vehicle's drive system (A-B) , I_d (t) - the current drawn by the drive system from the catenary,

Presented results were obtained by computer simulation for two variants: Variant 1 - one drive system with a single input filter (Fig. 2 a); Variant 2 - two drive systems that operate in parallel with one input filter (Fig. 2 b). Verification propulsion system models was carried out as the result of laboratory measurements and described in [13]. The plots shows the 50 Hz input impedance components of propulsion systems taken under consideration:

- impedance modulus ($|Z_{in}|$) - Fig. 4,
- impedance angle (angle(Z_{in})) - Fig. 5,
- impedance imaginary component (Im(Z_{in}))- Fig. 6,
- impedance real component (Re(Z_{in}))- Fig. 7,

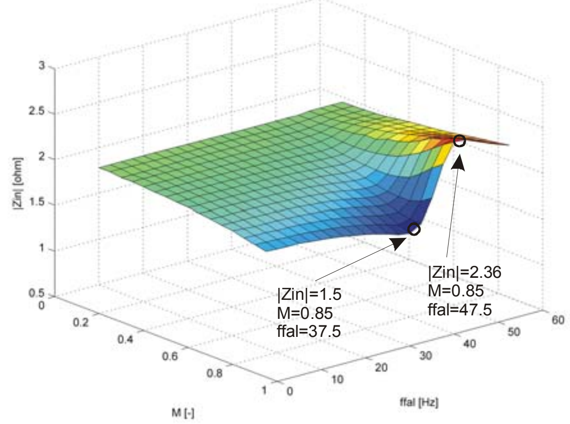
The variables in the graphs are: M- modulation index and f_{fal} - the frequency of the fundamental component of the inverter's output voltage. Modulation index M is defined as:

$$(2)\quad M = \frac{2 \cdot V_{out}}{U_{DC}}$$

where: V_{out} - the amplitude of the fundamental phase voltage of motor model.

This model is based on the modulation of the sinusoidal PWM with triangular carrier wave and. Analysed inverter's operating range was limited by terms of modulation M <0.1;0.85> with step dM = 0.05, and the frequency of the fundamental component f_{fal} in the range of <5; 60> with a step df_{fal} = 2.5 Hz.

a)



b)

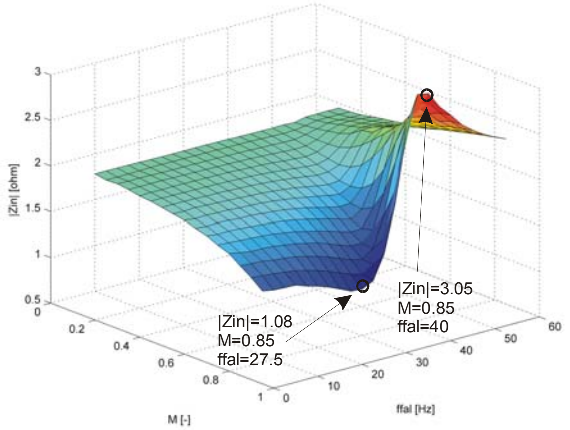
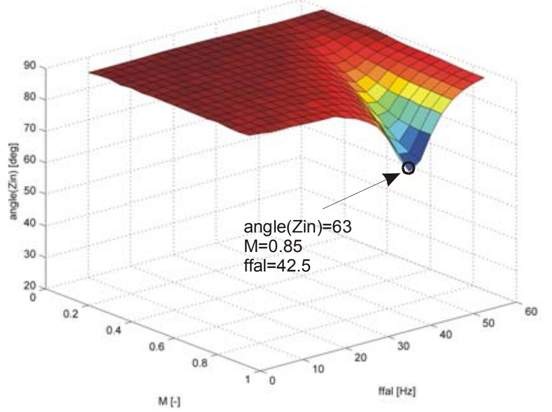


Fig. 4. The modulus of 50Hz input impedance, a) a single inverter, b) two inverters

a)



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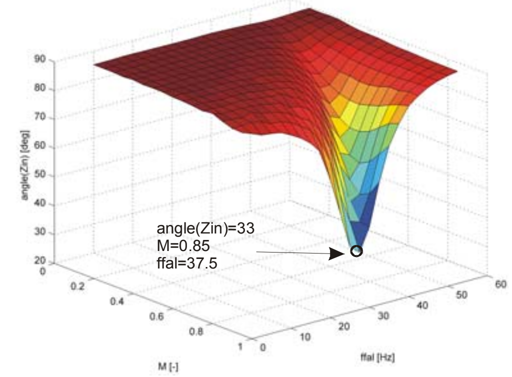
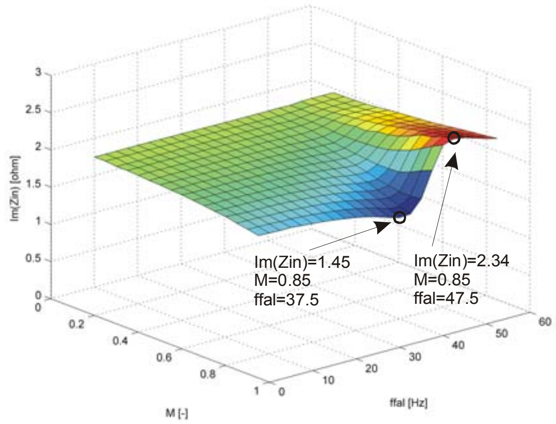


Fig. 5. The argument of 50Hz input impedance, a) a single inverter, b) two inverters

a)



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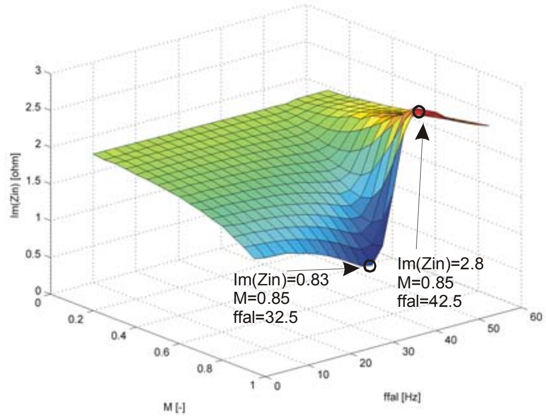
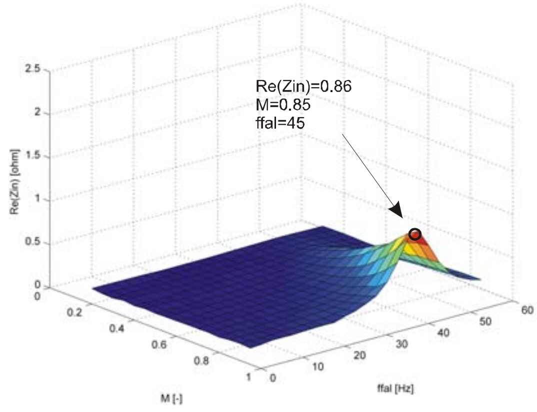


Fig. 6. The imaginary component of 50Hz input impedance, a) a single inverter, b) two inverters

a)



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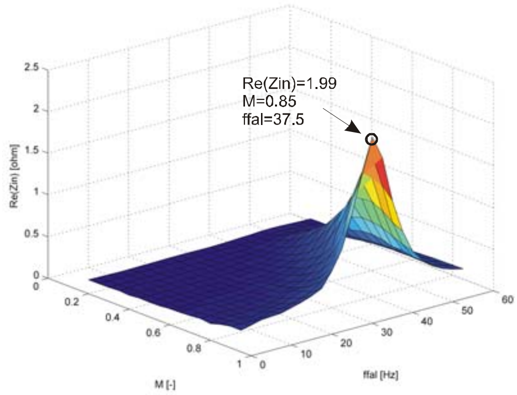

Fig. 7. The real component of 50Hz input impedance, a) a single inverter, b) two inverters

All analysed impedance components are stable as a function of f_{fal} for low values of M. In this inverter's operating area the drive's input impedance is equal to the input filter's impedance for both analysed configurations. Components fluctuations are escalating with increasing modulation index M. Most disturbing is the fact that there is a operating area where the inverter's input impedance module drops below the value of the input filter's impedance. In a system of two parallel inverters the fluctuations of Z_{in} components are significantly amplified what must be taken under consideration at the traction vehicle's designing stage. Most disturbing are the fluctuations of impedance modulus ($|Z_{in}|$ - Fig. 4). For a single inverter maximum of 50 Hz $|Z_{in}|$ equals 2.36 Ω for inverter's frequency f_{fal} = 47.5 Hz. Whereas for the two inverters max$|Z_{in}|$= 3.05 Ω and is displaced to the frequency f_{fal} = 40 Hz. This represents an increase of oscillation $|Z_{in}|$ from 118% to 152% relative to the input impedance of the input filter (~2Ω). More disturbing is the phenomenon of lowering the value of $|Z_{in}|$ from 1.5 Ω to 1.08Ω giving a change of oscillation down from 75% to 54% relative to the input filter's impedance. Also noteworthy is a clear change in the minimum impedance of the argument (from 66♂ to 33♂) and its location (from f_{fal} = 42.5 Hz to f_{fal} = 37.5 Hz) (Fig. 5). The proportion of change real and imaginary components shown in the diagrams (Fig. 6 and Fig. 7).

Summary

The traction vehicle's input impedance must be a parameter recognised at the vehicle's designing stage to properly determine its co-operation conditions as a receiver with the traction power system. The modulus of input impedance and the value of its remaining components depends significantly on the input filter's parameters but also on the inverter's operating point and main circuit topology as well which is presented in the article. The most interesting are the conclusions regarding the impact of the connection of two inverters traction drive systems to one common input filter. This resulted not only change the maximum and minimum values of impedance oscillations, but also a dislocation of the maxima and minima in the other areas of operation of the drive. The article presents the results for a specific model of drive system. Due to possible fluctuations in the input impedance modulus, similar analysis should be performed for newly designed tractions vehicles with regard to its parameters of used on-board engines, propulsion systems input filters. Moreover it may be necessary to provide the verification based on input impedance measurements during the vehicle's implementation to the service in the railway system [9], [11].

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