

Date of publication xxxx-00-0000, date of current version xxxx-00-0000.
Digital Object Identifier 10.1109/ACCESS.2017.10000

Quantitative feedback theory control to improve stability in dc catenary feeding traction and auxiliary drives

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This work was supported in part by the Agencia Estatal de Investigación (AEI) and the European Regional Development Fund (ERDF) under Grant DPI2017-88305-C2-3-R and the Comunidad de Madrid under Grant IND2013/END-9493.

ABSTRACT The progressive electrification of railways involves an increasing number of power electronic converters connected to the railway catenary, which may compromise its stability. Both the converter for traction and the converter for auxiliary power systems (APS) behave as constant power loads (CPL) and interact negatively with the catenary impedance producing voltage instability. This article applies quantitative feedback theory (QFT) to design an ac voltage controller for the APS converter that shapes the dc input admittance of the converter by performing only ac side-control without a dc-side feedback loop. The QFT enables to design a low order controller that satisfies multiple performance specifications in systems with high uncertainty as is the case of the train system. The proposed control guarantees catenary stability while ensuring ac output voltage reference tracking and providing robustness to unmodeled uncertainties. As an additional contribution, the article presents an algorithm for including input admittance specifications in the QFT design process. The proposed control has been evaluated on an experimental platform that recreates the train system. Experimental results show that the controlled system meets railway standards and correctly shapes the specified dc input impedance.

INDEX TERMS admittance shaping, constant power loads, dc catenary line, quantitative feedback theory, railway electrification, robust control, voltage control

NOMENCLATURE

C	Capacitor of the output filter in the APS.
C_F	Shunt capacitor of the LC filter between catenary and PCC.
d_{dq}	APS dq-axis small-signal duty cycles.
D_{dq}	Operating point of d_{dq} .
f_g	Fundamental frequency of the APS ac output voltage, v_C .
f_s	Sampling frequency.
$G_{VIdq}(s)$	Matrix of open-loop transfer functions.
$G_{VVdq}(s)$	Matrix of transfer functions between $\hat{v}_{Cdq}$ and $\hat{v}_{PCC}$.
$G_{Idq}(s)$	Matrix of transfer functions between $\hat{i}_I$ and $\hat{d}_{dq}$.
$\hat{i}_I$	APS small-signal dc input current.

$\hat{i}_{Odq}$	APS dq-axis small-signal ac output current.
I_{Odq}	Operating point of $\hat{i}_{Odq}$.
$K_{dq}(s)$	APS dq-axis voltage controller.
L	Inductance of the output filter in the APS.
L_{CAT}	Inductive term of the catenary impedance.
$LC_d(s)$	Admittance bounds.
L_{CCAT}	Distance between the train and the feeding substation.
L_F	Inductance of the LC filter between catenary and PCC.
M_{P_n}	Maximum overshoot for $T_{R_n}(s)$.
ω_g	Angular frequency of v_C .
$\omega_{n_{R_n}} = \omega_{d_{R_n}}$	Natural frequency for $T_{R_n}(s)$ and

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