Adaptive control of switched affine systems subject to unknown periodic exogenous input by harmonic synthesis.

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Historically, in power electronics, the first models established in frequency domains allowed to represent the harmonic analysis of the system only in steady state [Middlebrook 1976]. Subsequently, important efforts were made to take into account the transient regime and led to the development of two methods well known in the literature: "Generalised state space averaging" [Sanders 1991] and "Dynamic Phasors" [Mattavelli 1997], [Stankovic 2000]. With similar hypotheses, these methods are interested in the temporal evolution of signals and consider a sliding window of their Fourrier series in varying time. Thanks to a linearization around an operating point and to a truncation of this series, these methods can be used for stability analysis and the synthesis of control laws. Nevertheless, the effectiveness of these approaches depends on the number of harmonics taken into account and the validity of the simplification assumptions (linearization).
More recently, several methods have been developed for periodic systems: "Extended Harmonic Domain, (EHD)" [Rico 2003], "Dynamic Harmonic Domain, (DHD)" [Chavez 2008], [Chavez 2010], [Ramirez 20011] and finally "Harmonic state space (HSS)" [Wireley 1991], [Möllerstedt 2000]. In the linear periodic case, the idea is to use a transformation that leads to a representation of the dynamics of harmonics in the form of a linear time-invariant system (LTI) of infinite dimension. Stability analysis and synthesis of control laws are greatly facilitated. From the design phase of the controller, criteria concerning both the dynamic behavior of the system and the harmonic content of the signals can be considered [Hwang 2013, Ghita 2017].
Thanks to a unified formalism between all the above-mentioned methods, a notable advance on the control of these systems has been made possible by the establishment of necessary and sufficient conditions for the harmonic control of dynamic systems [Blin 2020a], [Thesis Blin 2020]. These necessary and sufficient conditions induce a particular choice on the structure of the harmonic controller and make it possible to guarantee the existence of an equivalent control in the time domain. This point is fundamental because many works in the literature do not allow this equivalence and the announced guarantees of stability are not demonstrated. Taking into account this NSC allows the establishment of a harmonic Lyapunov function [Zhou 2008] and also allows the derivation of stabilizing control laws in the periodic regime for the original system.

Objectives of the thesis :

This thesis is a continuation of the work developed in the thesis of N. Blin (CIFRE SAFRAN). It deals with a subject that is part of a theoretical research whose benefits go beyond the framework of this industrial collaboration.
Harmonic modeling offers a paradigm shift for the study of dynamic systems characterized by periodic or quasi-periodic steady state regimes, as it offers possibilities of analysis and control of the harmonics of a system without limit on the order of approximation (infinite order). It is also generic in the sense that the (exact) harmonic model does not depend on a particular choice on the period of the sliding window used; the model is valid regardless of the length of this window unlike classical tools used for example in the control of electrical machines (Park

transform, mark lq0) which depend on an operating point and which are approximations to order 1.

The first objective of this thesis is to develop a method for the synthesis of stabilizing control laws on a harmonic equilibrium for the class of switched affine systems subjected to a periodic or quasi-periodic exogenous input. Stabilization on a harmonic equilibrium means that the equilibrium is characterized in the time domain by a periodic steady state. Special attention on the establishment of criteria for making a choice on these equilibria will be necessary and may for example be guided by the minimization of the rate of harmonic distortion in addition to the main objectives of the control (tracking a trajectory, mean reference value, etc.).

Depending on the conditions of use of these systems, variations in the exogenous input and certain parameters must be considered. The dependency of the equilibria on these variations motivates the second objective, which concerns the adaptation of the controller. An important parallel in the time domain with the work of G. Beneux on the adaptive control of affine systems. The difference with these earlier works is that exogenous input is no longer assumed to be constant and unknown but quasi-periodic and unknown.

The preferred application targets concern AC-DC and DC_AC energy conversions on which the developed adaptive algorithms can be tested.

This theoretical subject requires from the candidate a solid knowledge of automation and mathematics (Lyapunov function control, etc.).

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