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On adaptive observers for state affine systems and application to synchronous machines [1]

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***Abstract*— A recently proposed adaptive observer for time-varying linear systems [21] is revisited on the basis of the well-known Kalman-like design for state affine systems [13], [4]. This approach in particular allows to emphasize the possible arbitrary rate of convergence in the design. The corresponding observer is applied to a problem of state and parameter estimation for a synchronous machine connected to an infinite bus, and its performances are illustrated in simulation.**
Keywords: State affine systems, adaptive observers, exponential convergence, synchronous machines.

I. Introduction

The problem of parameter identification has been extensively studied in many aspects during the last decades, including the problem of nonlinear systems, but generally without taking care of lack of state-space measurements. In the same time, the problem of state estimation for nonlinear systems has attracted a growing attention in the control community, and several results have been proposed to tackle this problem.

When dealing with the simultaneous estimation of state variables and constant parameters, the situation becomes more difficult, and the resulting problem of so-called *adaptive observer* has also attracted the attention of various control research groups. In short, an adaptive observer is a recursive algorithm allowing the joint estimation of the state and the unknown parameters in a dynamical system. Different approaches have already been proposed, in particular for linear systems (e.g. as in [7], [14] for early results, and [21] for a recent one), but also for nonlinear ones (see e.g. [2], [15], [5] and references therein).

Such adaptive observers are motivated by purposes of fault detection and isolation, signal transmission and adaptive control for instance. Here we are more particularly interested in such problems in the field of electrical power systems. There has indeed been a growing interest in this field during the last few years [10]. One of the problems in power systems is to preserve stability under changes in operating conditions, in particular due to network disturbances. Several control techniques are already available, but generally assuming that all components of the state vector are measurable and all the parameters are known.Such a situation is most likely not met in practice, and in turn hinders the possibility to apply the corresponding controllers.

The purpose here is thus to take advantage of recent developments in adaptive observers to discuss some algorithm for both state and parameter estimation for a class of nonlinear systems which can in particular be found in power systems: the considered class of systems is that of state-affine systems, and an illustration is given by the case of a synchronous generator connected to a infinite bus. The basic ingredients of our discussion are that of adaptive observer for linear time-varying systems as in [21] on the one hand, and that of state observers for state-affine systems as in [13], [4] on the other hand. Basically we show that by choosing a time-varying gain in the adaptive design of [21] (roughly as in [20]), we end up with an observer which actually corresponds to the well-known Kalman-like design for state-affine systems. This in turn yields a design with arbitrarily tunable rate of convergence. These results are illustrated in simulation for a synchronous machine.

The paper is thus organized as follows: in section II, previous results on adaptive observers for linear time-varying systems on the one hand, and state observers for state affine systems on the other hand, are recalled, highlighting the relationship between the two approaches. As an illustrative application, the case of a synchronous generator model is then considered in section III, where simulation results for the state estimation and simultaneously the identification of the mechanical power, are presented. Finally, some conclusions are given.

II. Background results and proposed interpretation

A. Exponential adaptive observer for linear time-varying systems

Let us recall here the basic result of [21] on adaptive observer design for linear time-varying systems of the following form:

$$\begin{aligned} \dot{x}(t) &= A(t)x(t) + B(t)u(t) + \Phi(t)\theta \\ y(t) &= C(t)x(t) \end{aligned} \quad (1)$$

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