Chapter 11
Intelligent Control and Optimal Operation of Complex Electric Power Systems Using Hierarchical Neural Networks

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ABSTRACT

This chapter is aimed at developing a unified neural network based framework that can be utilized in prediction and control of complex dynamic system behaviors. In particular, in power systems, accurate prediction of system load behavior provides vital information to allow for optimal planning and most economic operation of power systems; on the other hand, the real-time system stability must be maintained against various random factors, disturbances and contingencies. The hierarchical neural networks are studied in depth in the context of prediction, optimization and control; and unified design techniques are developed for providing control robustness, optimality and prediction accuracy as well. The unified methodology builds upon hierarchical neural networks, and may be utilized and extended for other practical applications.

INTRODUCTION

The derivation of a mathematical model from physical laws according to the use of the model (e.g., for control), is most basic here to determine the mathematical structure. For example, it is shown (Laszlo, 1972) that a close connection exists between dynamic identification of an environment and its control. System identification itself is a well developed area of system theory. The need of mathematical representations in many aspects of the real world dictates the importance of system identification. In a way, it may be said that identification is a link between the mathematical-model world and the real world.

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For characterization of the cause and effect links of an observed plant, it is often assumed that the plant can be described by a model whose structure is known, or in other words, the plant is associated with a given form of parameterization, but the values of the parameters are assumed to be unknown. The parameters of the model are tuned in such a way that the behavior of the model approximates that of the plant. Differential equations, difference equations, and state-space representations are some examples of most widely used models. An excellent treatment of system identification in theory and applications may be found in (Ljung & Söderström, 1983), (Ljung, 1987). Note that identification may be categorized into off-line identification and on-line identification. The former one refers to a separate procedure by which a model (usually of given structure) is constructed based on a batch of data collected from the real system. The latter one refers to a procedure by which a model (again usually of given structure) is constructed and updated based on the most recent available data collected from the system in operation. Off-line identification may be sufficient for time-invariant systems. The need for on-line identification is seen in cases where the properties of the observed object are time-varying. For control purposes, two different approaches exist. One is the so-called indirect control by which the control action is adjusted based on the on-line identification of the plant. The other is the so-called direct control by which the control action is adjusted to improve a performance index involving implicit identification. Note that for both approaches, efforts have to be made for identification of the behavior of the plant even when control action is being taken based on the most recent available information about the plant. In a way, it may be said that control and identification are inter-dependent (Irwin, et al. 1995), (Haykin, 2001).

No matter what kinds of identification and adaptive control schemes are used, the basic requirement is to keep the overall system stable. Stability is always an important issue for design of adaptive control. Stability analysis of adaptive systems is still quite a challenge. In general, the analytic solution of dynamic nonlinear systems is usually impossible so that indeed, general results on adaptive control of nonlinear systems are very few. It is true that, though, adaptive control can be designed for some general dynamic nonlinear systems, for example, feedback linearizable nonlinear systems. On the other hand, adaptive control of linear systems was ever an extensive research subject, and numerous results are available. An attempt to present a unified framework of the currently well known results for stable adaptive linear systems is made in (Narendra & Annaswamy, 1989). Adaptive stabilization of nonlinear systems is overviewed in (Praly et al., 1991) where the nominal control explicitly expressed in terms of parameters is assumed. It is noted that either available results for dynamic linear systems are not adequate for real nonlinear systems or general results for dynamic nonlinear systems which are very useful are scarce. A simple class of nonlinear systems, bilinear systems which is linear in state and control but are jointly nonlinear, possess convenient structure properties, and hence make mathematical treatments possible. It is illustrated in (Mohler, 1973), (Mohler, 1991a), (Mohler, 1991b) that many real nonlinear systems could be treated approximately as bilinear systems, and the control design procedures and stability analysis theories developed have played crucial roles in designing proper controls for these systems. It is shown in (Mohler, 1973) that controllable linear systems may not be controllable with physical constraints on control while the controllability of bilinear systems of the same order could be achieved. Roughly speaking, bilinear systems are more controllable than linear systems. In many practical problems, theory of bilinear systems has found its successful applications (Mohler, 1991b). Recently, interest in application of bilinear system theory to power systems was observed. It is shown in (Rajkumar & Mohler, 1994) that the transmission network of power systems when controlled by a variable series capacitor, (a simplified model for the thyristor-controlled series capacitor (TCSC), one kind of the popularly used flexible ac transmission systems (FACTS) devices), can be modeled as a