Integrated Cellular Neural Networks for Wide Area Monitoring and Control of Smart Grids

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Abstract -- Monitoring of power system components is one of the ways by which status of a system can be assessed. Analysis performed on the output of monitoring systems can provide important information about the state of the system and its trajectories. The information from monitoring system enables sensemaking leading to situational awareness. Development of wide area monitoring system is, hence, important for situational awareness in a smart grid. The input from such a monitoring system enables wide area control systems to take predictive control actions to keep the system stable during disturbances. In this study, a multi-layered integrated cellular neural network (CNN) has been used for predictive state estimation of various parameters in a smart grid. These different parameters are identified or predicted by each layer of the CNN. The prediction of various power system parameters by these layers constitutes the wide area monitoring system for the smart grid. A control layer based on dynamic stochastic optimal power flow (DSOPF) is proposed which provides auxiliary predictive control signals to the system.

INTRODUCTION

Increasing penetration of intermittent renewable energy results in increased variability and uncertainty. Traditionally optimal power flow dispatch is updated approximately every 5 minutes based on load/generation forecast for the next period. Any unforeseen changes between dispatches are handled by linear controllers with little or no system wide optimization. With the advent of synchrophasors, wide area measurement based control schemes are now possible. Dynamic stochastic optimal power flow (DSOPF) is one such method proposed as a possible means to improve grid dynamics [1]. In this study, DSOPF is implemented on the principle of adaptive critic designs (ACD), where an actor formulates the optimal control strategy with information available at current time and a critic evaluates the control strategy of the actor [2]. In model based ACD, there is also a model network which learns the plant dynamics. In this study, actor, critic and model are built using neural networks (NNs). Action network provides the optimal control strategy for the next time step by using plant state variables at the current time step. Time delayed values of optimal control strategy are given as inputs to monitoring layer to improve its prediction model. Predicted values for future state variables from each layer are in turn used by control layer to formulate control strategy for the future states. The proposed scheme thus looks forward one or more time steps into future, anticipates how things are going to change and devises an optimal control strategy based on that knowledge.

NN have been successfully implemented as state predictors and neurocontrollers in the areas of wide area monitoring and control [3]. However, they are not scalable because their performance starts to degrade as size of the system and number of input/output parameters increases. Cellular neural networks (CNN) are a class of NNs with a decentralized architecture that divides the problem into sub-problems which is potentially scalable. An integrated CNN consists of multiple interconnected layers of CNNs each responsible for the prediction/estimation of one parameter of the system. In the proposed integrated wide area monitoring and control of smart grids, DSOPF layer will form the control layer. Recurrent neural networks (RNNs) have been used to model actor, critic and model network. An integrated CNN as shown in Fig. 1 is used for developing the wide area monitoring system. The outputs of the monitoring system is then utilized by the ACD framework based DSOPF for providing control signals. As an example application of integrated multi-layered CNN, Fig. 2(a) shows the output of CNN layer for generator power output predictions; Fig. 2(b) shows the output of CNN layer for speed deviation predictions.
Figure 1. A multi-layered integrated cellular neural network showing different layers used for estimation/prediction of various power system parameters.

Figure 2. Some preliminary results showing application of multi-layered integrated CNN.

References

1. Venayagamoorthy GK, “Dynamic, Stochastic, Computational and Scalable Technologies for Smart Grid”, IEEE Computational Intelligence Magazine (Special Issue on Smart Grid), Vol. 6, No. 3, August 2011, pp. 22-35